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EVALUATION OF HARVESTING METHODS AND MATURITY ASSESSMENTS IN WHEAT AND BARLEY

by

© SHAUNA C. SOMERVILLE

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF PLANT SCIENCE

EDMONTON, ALBERTA

SPRING, 1978

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Evaluation of Harvesting Methods and Maturity Assessments in Wheat and Barley submitted by Shauna C. Somerville in partial fulfilment of the requirements for the degree of Master of Science.

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Supervisor

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Date December 14 1977

ABSTRACT

Several combine-orientated harvesting procedures were evaluated for applicability to yield testing in cereal breeding programs. The performances of seven spring wheat (Triticum aestivum L. em Thell) and of six spring barley (Hordeum vulgare) genotypes for several commonly measured characters were used to assess the effects of alternate harvesting practices. Harvesting treatments had a significant effect both upon the mean values and upon the relative performances of the genotypes for all characters. Therefore the introduction of combine harvesting practices into yield testing can be expected to influence the selection of superior genotypes within a test.

Five measures of maturity, (1) days from seeding to 35%mcwd, (2) days from seeding to heading, (3) field rating, (4) Delmhorst G-6c reading of moisture content, and (5) days from seeding to swathing ripeness, were compared with the objective of selecting a method improving the sensitivity of large scale selection of maturity types within a cereal breeding program. Once-over testing of lines at the physiological maturity of the early genotypes, using a small dielectric moisture meter, is potentially a powerful method of selecting early maturing lines of both wheat and barley. The Delmhorst G-6c meter studied in this test was not accurate enough for this purpose.

Multiple regression analysis of both wheat and barley drying curves supported the model of ripening in cereals proposed by Meredith and Jenkins (1975). Regression analysis relating

fluctuations of several weather parameters to deviations from estimated drying curves proved to be a useful method of quantifying the influence of local, daily weather on the drying process.

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INTRODUCTION

I. Harvesting Methodology

Yield is a major concern of all breeding programs; whether it be the improvement of yielding ability per se, or the maintenance of yield levels in conjunction with the alteration of quality characters. For this reason, extensive yield trials, generally during the later stages of breeding programs, are performed. In Western Canada, yield testing in most cereal breeding programs consists of preliminary trials carried out by individual breeders, as well as regional and interprovincial Cooperative tests conducted by the Canada Committee on Grain Breeding in cooperation with all cereal breeders in Western Canada. The accumulation of several location-years of yield data about experimental lines allows for accurate assessments of true yielding ability of the lines over a wide range of environments.

Standard methods of yield testing have generally been adopted by plant breeders in Western Canada. The experimental designs commonly employed are those of the randomized block and lattice designs with three to four replicates. A standard four row, rod-row plot is the basic harvest unit. The center two rows are harvested; the outer rows act as a buffer zone, minimizing the effects of interplot competition. The harvested material, including the straw, is allowed to dry before threshing. Test weight and seed weight are commonly measured on the threshed grain.

Until recently much of the work involved in yield trials

was done by hand. However, of late, there has been an increasing trend towards the use of mechanized harvesting methods. This is particularly true of yield trials wich are highly standardized and therefore amenable to such methods. Increasing labour costs, a shortage of labour during the autumn harvest months, and a short harvest period are three factors necessitating the move to mechanization of harvesting processes in breeding programs. The desirability of large breeding programs is another factor, in conjunction with the above three factors, prompting plant breeders to take an interest in mechanized harvesting procedures. Mechanized harvesting operations may also be advantageous in that they minimize sample handling and, therefore, may be faster, less costly and more efficient.

Out of this interest in mechanized harvesting techniques arose the need to assess alternate harvesting methods before they are applied to yield testing. The harvesting methodology study reported herein was designed to answer some of the following questions relating to mechanized harvest procedures. (1) What are the advantages and disadvantages of mechanized harvesting for cereal breeding programs? (2) Is the assessment of experimental lines according to standard criteria the same under conventional and mechanized harvest procedures? (3) What bias, if any, is introduced into the evaluation of lines harvested by alternate procedures? (4) Can a mechanized harvest procedure be developed optimizing the advantages of speed and efficiency, while minimizing any disadvantages? The performances of several well characterized cultivars harvested by a variety of alternate harvesting methods were compared. Seven wheat and six barley genotypes representing a wide range of types were chosen for this purpose. To determine

which characters were differentially influenced by the harvesting regimes, several standard characters, including yield, test weight, seed weight and germination capacity were used to evaluate the performance of the cultivars.

II. Maturity Assessments

Central Alberta, with an average of 100 - 120 frost-free days, is generally considered a short season area for cereal production (Longley, 1967). For this reason, the cereal breeding programs centered at the University of Alberta place a considerable emphasis on the maturity of experimental lines of wheat and barley. Early maturing types are required that will both yield well and mature within a relatively short growing season. Genotypes breaking the commonly observed association between high yield and late maturity must be developed for this region of Alberta. Therefore, even small differences in maturity among lines become important to the breeding program. Some doubts have been raised as to whether current methods are sufficiently accurate to detect small differences in maturity (Briggs, 1976). The currently employed measures of maturity are (1) days from seeding to heading, (2) days from seeding to late dough stage (swathing ripeness), and (3) a visual rating of relative maturity. Thus the impetus for the second part of this study arose from the need for accurate measures of maturity in a short season climate. It was also deemed necessary to develop a method of quantifying maturity prior to the harvesting period in order to spread the work load at this time.

The result of this interest in accurately quantifying the maturity of wheat and barley was a study of the drying down or ripening process under short growing season conditions. Drying curves were constructed for several wheat and barley cultivars from moisture contents determined at various times during grain-filling and desiccation. These curves were used to study the nature of the drying process and the influence of several weather parameters on this process. In addition, the results of the current methods of maturity evaluation were compared to those obtained from the drying curves for the purpose of assessing the reliability of the presently employed methods.

LITERATURE REVIEW

I. Kernel Development

An underlying assumption of both aspects of this study was a basic knowledge of kernel development. Without this knowledge precise definitions of maturity or ripeness would not be possible; nor would there be any basis for understanding the effects of alternate harvest methods.

The earliest studies of kernel development in cereal crops are those of Brenchley and Hall (1909) in wheat, and of Harlan (1920) and Harlan and Pope (1922, 1923, 1926) in barley. The detailed histological and chemical studies of Brenchley and Hall (1909) arose from an interest in the nature and the development of the "strength" of wheat flours. They found that dry matter, nitrogen, ash and phosphoric acid gradually increased in the kernel until one week prior to harvest ripeness. During the last week before cutting some loss of dry matter, due in part to losses from respiration, was observed. Moisture content of the caryopsis followed three phases: an initial phase of increasing moisture per kernel; a second period of constant moisture content; and a final desiccation period. Brenchley and Hall (1909) concluded that kernel development occurred in three stages. In the first stage the pericarp tissue dried and contracted. The second stage was one of starch and storage protein deposition and endosperm filling. The final and ripening stage was a period of desiccation. Few chemical changes occurred during the final period, although the authors noted the

transformation from nonprotein to protein nitrogen continued throughout this stage.

Harlan (1920) carefully followed the development of Hannchen barley kernels from flowering to maturity. Harlan considered maturity as that point in time when dry matter accumulation ceased. In Hannchen barley maturity occured at 42%mcwb (moisture content - wet basis). Daily samples of Hannchen kernels were analyzed for dimension, volume, and contents of dry matter, moisture, nitrogen and ash. Dry matter and nitrogen accumulated steadily until maturity. Moisture content also increased until maturity, but at a rate slower than dry matter accumulation, such that the proportion of moisture in the kernels declined steadily to maturity. Although Harlan's work did not include observations during the ripening phase, his results from barley agreed with those of Brenchley and Hall (1909) in wheat, for the periods studied.

Harlan and Pope (1922) conducted an experiment to determine the earliest stage at which barley kernels could be harvested and still maintain their capacity to germinate. The authors demonstrated that all seven cultivars under test had acquired the capacity to germinate and produce normal, although somewhat small, seedlings by six days post-anthesis. This test demonstrated that development of the embryo was very rapid. As an extension of this study, Harlan and Pope (1926) examined the development of immature barley kernels removed from the plant. They found that most kernels, if attached to a length of culm and stored under cool, humid conditions, continued to develop for about four days following harvest. Similar development was not observed in kernels removed from the spike and air dried.

In a second study of barley kernel development, Harlan and

Pope (1923) followed daily changes in the kernel moisture content from fertilization to maturity. The conclusion drawn by the authors in this experiment was that changes in moisture content followed three distinct phases analogous to those described in wheat by Brenchley and Hall (1909). Harlan and Pope (1923) also commented that weather conditions can influence kernel development and cited two examples. Fluctuations in weather brought about concomitant changes in moisture content. Also, long, cool growing seasons favored the formation of plump kernels.

Woodman and Engledow (1924) published a detailed study of the chemical changes that occur during the development of wheat kernels. They measured fluctuations in several constituents over the course of development from about 80%mcwb to 16%mcwb. The characters assayed included moisture content, dry matter, total nitrogen, the nitrogen content of various extracts (neutral salt, alcohol soluable and alkali soluable extracts), amino acid content, ash, crude fat, crude fiber and carbohydrates. Observations of changes in dry matter and moisture content confirmed those made previously by Brenchley and Hall (1909), Harlan (1920), and Harlan and Pope (1923). The preoccupation of Woodman and Engledow (1924) with nitrogen determinations arose from an interest in the development of proteins contributing to bread making quality in wheat flours. Gluten formation began when dry matter accumulation ceased. Measurements of major constituents showed that total nitrogen increased until harvest ripeness. However, crude fiber, ash and the carbohydrates increased only until physiologic maturity and then plateaued. Crude fat tended to peak during the period of endosperm filling and then declined to harvest ripeness.

Wellington (1956), in a study of the germinative capacity of wheat kernels during development confirmed the earlier results described

above. He documented changes in dry matter and moisture content for both the intact kernels and for the embryo during development. Wellington (1956) observed that the embryo lost moisture in a manner different from the whole kernel. Whereas the whole kernel declined in percent moisture steadily from two weeks post-anthesis until harvest ripeness, the embryo showed a decline of percent moisture values in two stages separated by a plateau at seven to nine weeks post-anthesis. Unlike Harlan and Pope (1922), Wellington found that wheat kernels did not acquire the capacity to germinate until five to seven weeks post-anthesis. Differences in the preparation of the kernels for germination testing may account for the lack of agreement between the two sets of results. Harlan and Pope (1922) dried the immature kernels prior to testing; however, Wellington (1956) tested samples immediately for germination capacity, with no drying. In the same paper, Wellington (1956) stated that desiccation may have an important influence on the germinative ability of wheat kernels.

More recent studies of kernel development in cereals have emphasized fluctuations in specific constituents of the caryopsis other than dry matter and moisture content. Two New Zealand workers, Meredith and Jenkins (1970, 1975, 1976) have, however, taken an interest in these two basic components of the kernel. They found that in a wide range of cereal crops grown under diverse conditions, dry matter accumulated at a steady rate of about one to two milligrams dry matter per day until physiological maturity. In additon, Meredith and Jenkins (1970, 1976) demonstrated that in some cultivars (eg. the New Zealand wheat Hilgendorf and the French wheat Capelle-Desprez) dry matter did not remain constant after the kernel had reached physiological maturity but fluctuated. The authors, therefore concluded that ripening kernels

were metabolically active. A survey of moisture loss in several cultivars of the cereal crops wheat, barley and oats reaffirmed earlier descriptions of the occurrence of three phases of moisture content and of the steady decline in percent moisture content during kernel development (Meredith and Jenkins, 1975). Based upon these observations Meredith and Jenkins (1975) proposed a model for the ripening process in cereals in which they have suggested that the loss of moisture from the desiccating kernel is an active physiologic process.

The results described above can be summarized as follows. Kernel development in wheat and barley follows a similar pattern with respect to changes in the major constituents dry matter and moisture. Dry matter content per kernel increases gradually from shortly after anthesis until physiologic maturity (35 - 40%mcwb), when accumulation ceases. During the ripening stage which follows, dry matter content may remain constant, decline slightly or fluctuate. Moisture content per kernel follows three phases. The initial phase corresponds to the rapid accumulation of moisture in the developing kernel. This phase is followed by a period of little or no change in moisture content. The final phase is a period of rapid desiccation. The duration of each phase is influenced by genotype and may be influenced by weather factors (Meredith and Jenkins, 1975). The combination of changes in these two major components of the kernel leads to a steady decline in proportion of moisture, and an increase in the proportion of dry matter over the course of kernel development. During phase one, dry matter accumulates more rapidily than moisture, resulting in a decline of percent moisture content and an increase in percent dry matter content. The continued deposition of dry matter, accompanied by static moisture content in phase two, brings

about a further decrease in percent moisture content and increase in percent dry matter. The decline in percent moisture content and the increase in percent dry matter in phase three are produced by a loss of moisture from the kernels; the dry matter content remaining fairly constant. Figures 1 and 2 diagram these changes in moisture and dry matter content, and proportion respectively.

As mentioned above, more recent experiments relating to kernel development have been concerned primarily with fluctuations in specific components. The starches have been studied extensively because of their obvious relation to yield and to flour quality. Protein is another well studied constituent of cereal kernels. The quality of bread wheats and of malting barleys as well as the nutritional value of feed grains is determined by the nature and quantity of protein material found in mature grains. In addition, several people have monitored the pattern of development of various enzyme activities (Bushuk and Hwang, 1971; Prentice et al.,1971; MacGregor et al.,1971; Duffus and Rosie, 1977) and minor components of the kernel (Dodds and Warder, 1970; Skarsaune et al., 1970; Duffus and Rosie, 1976a, 1976b; Radley, 1976) in order to gain some insight into the physiological processes determining kernel development.

Starch, as a major component of dry matter at maturity, is an important determinant of yield (Jenkins et al., 1975; Jenner and Rathjen, 1975). Starch deposition during kernel development has been described both from histological and from chemical studies. The patterns of starch deposition in barley (Harris and MacWilliams, 1957; MacGregor et al., 1971) and in wheat (Bice et al.,1945; Jenkins et al., 1975; Loney et al., 1975; Jenner and Rathjen, 1975) are similar. The description

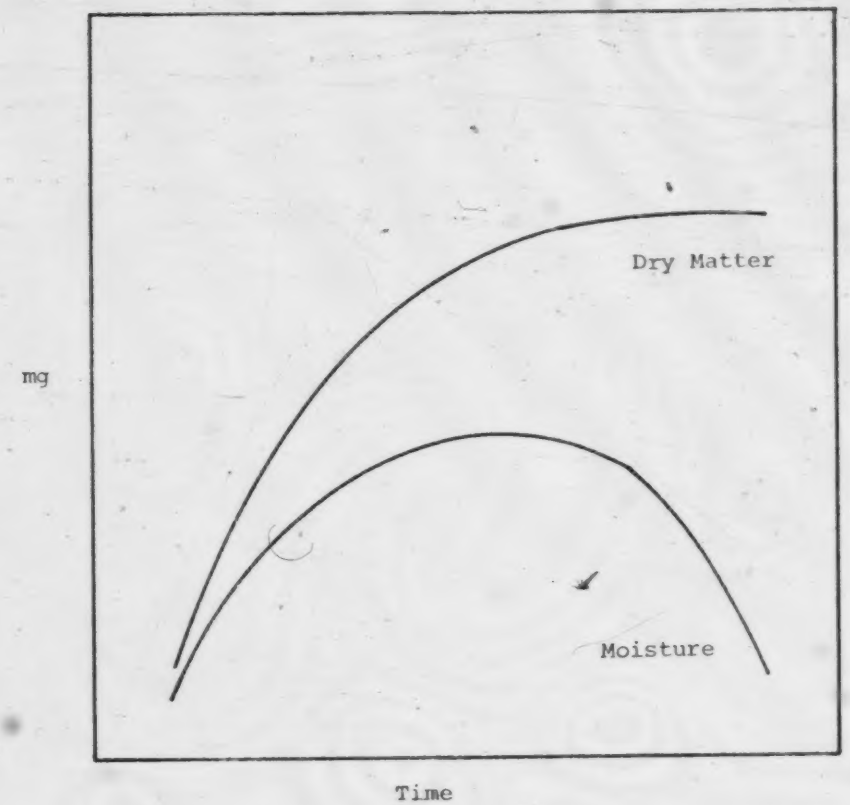

Figure: 1 Dry Matter Content and Moisture Content in the Developing Kernel

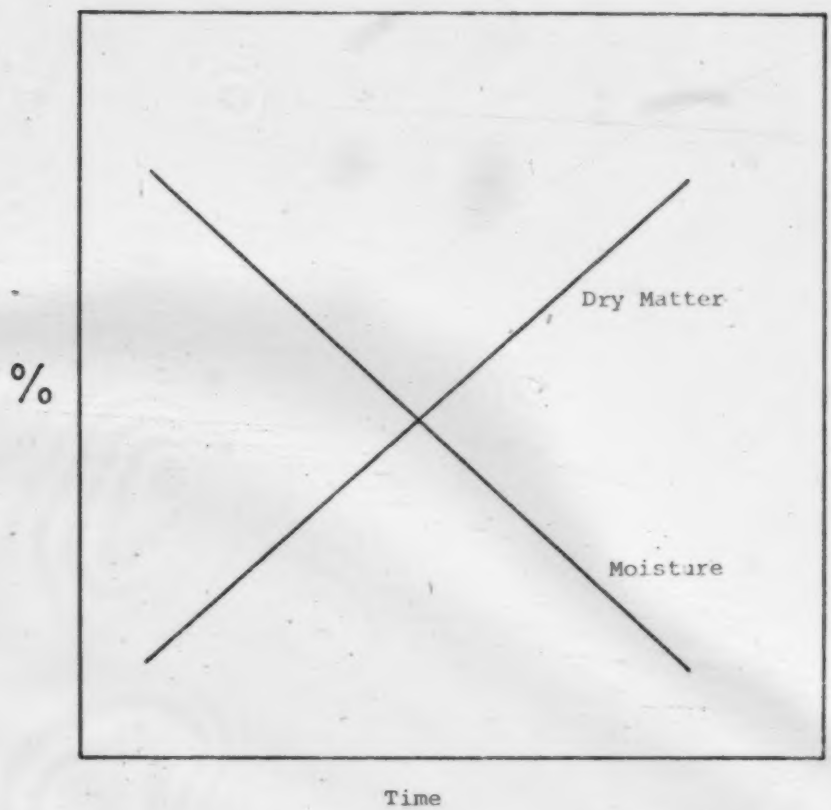

Figure: 2 Proportions of Dry Matter and Moisture Content in the Developing Kernel

offered by Jenkins et al., (1975) is as follows. Starch deposits may be found in the pericarp of very young kernels, thus, the starch content of kernels does not begin at zero. Filling of the endosperm cells begins several days after fertilization, shortly after the endosperm cells have completed cell wall formation. Early in kernel development, a slight decrease in starch content may be observed. This coincides with the loss of starch and moisture from the pericarp. Starch is laid down in the center of the kernel initially and the last depositions appear in the peripheral cells on either side of the crease (Sandstedt, 1946). The histological work of Sandstedt (1946) showed that starch granules begin as small bean shaped nuclei. These granules then grow into large, lenticular granules. Later in development, small, spherical starch granules are deposited, filling the spaces between the larger granules. Starch accumulation abruptly ceases at physiological maturity. This pattern of starch deposition and cessation of deposition is very similar for many cereal crops. On the basis of these observations Jenkins et al. (1975) have suggested that some physiological mechanism is acting to limit the accumulation of any further starch. Developing this idea, Jenner and Rathjen (1975) have suggested that inactivation of starch forming enyzmes, rather than a lack of sucrose substrate is the cause of the cessation of starch deposition.

Protein material, although it never accumulates to the same extent as starch, is nonetheless very important in kernel development. Throughout development functional proteins (enyzmes) are present for metabolism and for synthesis of storage materials (MacGregor et al.,1971; Smith, 1972; Jenkins et al., 1975; Flint et al., 1975; Duffus and Rosie, 1977). Proteins are also important as reserve materials in cereal kernels,

and these storage proteins determine the final quality of many cereal grains. In wheat, the glutens and other related proteins influence the bread making properties of the derived flour. Final protein content and composition is important for nutritional reasons in wheats for both human and animal consumption. Malting grade barleys differ from wheats in that low protein levels are generally desirable; feed barley, like feed wheat, is nutritionally more acceptable with high protein levels. Although both the functional and storage proteins are important determinants of kernel development, it is the quantity and composition of the reserve proteins that determines the final quality of the cereal grain.

Protein accumulates in the developing kernel in a pattern similar to starch and dry matter. Working with Conquest, a spring planted, malting barley, MacGregor et al. (1971) found that protein content increased steadily from about ten to thirty-five days post ear emergence (30%mcwb), when protein content plateaued at a level of about five mg/kernel. This result is consistent with the findings of several other researchers (Woodman and Engledow, 1924; Salem et al., 1975; Flint et al.,1975). There have been some reports in the literature suggesting that although the content of protein in the kernel does not change appreciably after the kernels have reached physiological maturity, metabolism of the proteins may continue beyond this point. In barley, the composition of the proteins may undergo some alterations even though no new protein is synthesized (MacGregor et al., 1971; Pomeranz et al., 1971). Harvesting malting barley at physiological maturity is generally not recommended because of the loss of quality incurred (Koenig et al., 1965; Dodds, 1967; Pomeranz et al., 1971). The results from research on the development of quality characteristics in wheat are equivocal. Some

researchers have demonstrated that both physiological and functional (quality) maturity are attained simultaneously at about 40%mcwb in wheat (Scott et al., 1957; Salem et al., 1975; Yamazaki, 1976). Spillane (1973) has reported that bread making quality improves from physiological maturity to harvest ripeness.

Kernel development in common cereals like wheat and barley follows three broad phases. The initial phase involves changes in the pericarp, and the formation of the endosperm. During this stage, most of the starch of the kernel occurs in the pericarp, and the major proteins are enzymatic in nature (Sandstedt, 1946; Jenkins et al., 1975; Flint et al., 1975). During the second phase reserve materials, the starches and proteins are formed and deposited (Sandstedt, 1946; Jenkins et al., 1975; Flint et al., 1975). The end of the second phase indicates the attainment of physiological maturity. The final phase is primarily a desiccation or ripening period, although some changes in the kernel may take place (Meredith and Jenkins, 1970, 1976; Dodds and Warder, 1970; MacGregor et al., 1971; Pomeranz et al., 1971; Loney et al., 1975).

II. Harvesting Methodology

Historically, the combine harvester is a recent introduction to agriculture; replacing the binder-threshing operations shortly after the turn of the century. Early symposia related many of the advantages and disadvantages of combines still considered relevant today with more sophisticated machinery (see Agr. Eng. 8, 1927 and Agr. Eng. 10, 1929). Although much enthusiasm for the new combine harvester was expressed in

these early reports, some reservations as to its usefulness in unevenly matured fields, in excessively weedy fields and in high moisture content grain were reported (Jones, 1927; Jones, 1929; Black, 1929; Hardy, 1929). The swathing and pickup operation commonly utilized in Western Canada was being developed at that time by engineers in Saskatchewan (Hardy, 1927, 1929; MacKenzie, 1929). The primary advantage cited for the swathing operation was the reduction in length of season, thereby reducing risks of crop failure associated with short seasons and unpredictable weather.

As early as 1930, researchers expressed interest in employing the combine harvester in experimental cereal plots; thereby, mimicking current farming practices and obtaining more realistic yield results (Aicher and Hallsted, 1930). Early researchers used small commercial combines to harvest yield trials (Aicher and Hallsted, 1930). Today however, the use of commercial combines is not practical on a research scale. Large plots are required for commercial scale machines to function efficiently, and large tracts of land are necessary for maneuvering space. As a commonly accepted practice, yield trials in Western Canada are conducted on standard four row, rod-row plots from which the center two rows are harvested (harvested area: 2.3 m^2). Often sufficient seed for planting larger plots is not available. Also the increasing land costs and the expanding size of many cereal breeding programs dictates that land is always in short supply. These two factors, the small size of plots and the scarcity of land have prompted many researchers to use alternate methods of harvesting. Various engineers concerned with experimental plot equipment have designed a variety of machines for harvesting research plots (Jensen and Willis, 1952; Wolfe and Grafius, 1965; Hergert and Hurd, 1967: Hergert, 1970; Thompson and Wells, 1975).

Experimental plot combines have been designed and released by several manufacturers. Notable in this list are Hege (D.B.R.), Kompa (Japan), Universal (Austria), and Kincaid Equipment Manufacturing (U.S.A.) (Craigmiles, 1976).

The advantages and disadvantages of swathing and straight combining from the view point of a cereal breeder are presented in a list below.

Swathing - Advantages

1. Saving of time

Grain generally dries more rapidly in a swath than standing, resulting in a saving of one to seven days over straight combining operations (Schwantes, 1929; Cromer et al., 1929; Hardy, 1929; Dodds, 1957, 1967; Robertson, 1956, 1957; Koenig et al., 1965; Dodds and Pelton, 1969; TeKrony et al., 1976). This saving in time can be particularly important in several situations. In short season climates or in areas where harvesting season weather is often unpredictable, the risk of crop failure is reduced (Hardy, 1929; Dodds, 1967). The saving in time in harvesting operations can be used for fall field operations (Aicher and Hallsted, 1930). Double cropping situations can also take advantage of the saving in time offered by the swathing technique (TeKrony et al., 1976).

2. Harvesting unevenly ripened material

Swathing procedures can be useful in harvesting both unevenly matured fields and yield trials containing experimental lines of a wide range of maturities. Grain in the swath dries to a uniform moisture content suitable for threshing (Dodds, 1967).

3. Reducing losses during weather disturbances

Grain in a swath withstands extreme weather conditions (rain, hail, snow, wind, storms) during the harvest season better than standing grain (Robertson, 1957; Dodds, 1967). Losses due to lodging and shattering under such conditions are reduced. Also moisture added by precipitation is lost from grain in a swath more rapidly than from a standing crop (Robertson, 1956, 1957; Dodds, 1967; Dodds and Pelton, 1969).

4. Reducing losses due to lodging

Because a large number of lines may be screened in cereal yield trials, weak strawed lines may be encountered. Swathing at early stages often overcomes the problems of reduced quality and yields associated with lodged crops. Better estimates of true worth for lines tending to lodge can be obtained when such lines are harvested by swathing.

5. Reducing shatter and header losses

Dodds (1974) demonstrated that losses due to shattering and header losses during harvesting are minimized if the crop is cut at higher moisture contents, such as is possible with swathing.

6. Mixing of seed is minimized

Seed mixing during harvesting operations can retard the development of new lines in a breeding program. With swathing operations, threshing procedures are separated in time from cutting procedures. The equipment and time for proper threshing and cleanout between threshing each genotype is available, and seed mixing is minimized.

Swathing - Disadvantages

1. Damaging quality

Swathing barley above 25-30%mcwb depresses malting quality

(Koenig et al., 1965; Pomeranz et al., 1971). The bread making quality of wheat may (Spillane, 1973) or may not (Scott et al., 1957) be damaged by swathing at 35%mcwb. Soft white wheats may be swathed at physiological maturity without deleterious effects on cookie making quality (Yamazaki, 1976).

2. Reducing test weight

Low test weights have been reported for swathed grain (Pomeranz et al., 1971). Suboptimal test weights may adversely influence the selection of lines as test weight is an important component of quality in the grain trade (Pushman, 1975; Ghaderi et al., 1971).

3. Weathering

A crop left lying in a swath for too long weathers (loses color and quality) more readily than a standing crop.

4. Grain drying

Artificial grain drying is necessary to ensure safe storage if the crop is threshed prior to drying to 14%mcwb (Caldwell and Davies, 1957; Smith, 1969; Wallace and Sinha, 1969). The germinative ability (Webster and Dexter, 1961; Watson, 1970) and quality (Finney et al., 1962) of cereals may be reduced by improper drying. Thus proper drying procedures must be observed in order not to introduce error into the assessment of experimental lines. This drying adds an additional cost to the expense of harvesting (Audsley and Boyce, 1974).

5. Multiple handling stages

In swathing operations the cutting and threshing operations are separated in time. This spread of the harvesting operations may be disadvantageous. Evaluation of lines is delayed, and subsequent selection of material for winter nurseries affected (Briggs, 1976).

Straight Combining - Advantages

1. Minimizing handling

Straight combining operations minimize handling as cutting and threshing are carried out simultaneously. When handling many experimental lines in yield trials, this may become an important consideration. Also yield data are available immediately for early evaluation and assessment of lines.

2. Reducing labor needs and costs

Much less labor is required for straight combining in research operations than the currently employed swathing, bagging and threshing operations.

3. Fast

Reduced handling and labor requirements associated with straight combining make it a very fast system of harvesting given proper conditions. This factor is very important in short season areas where the time available for harvesting yield trials is minimal.

Straight Combining - Disadvantages

1. Lacking flexibility

Straight combining lends itself to once-over harvesting operations because it is fast. However, this type of harvesting may not be possible if a wide range of maturities are displayed by the experimental lines within the nusery. For example, harvesting at a median data suitable for medium maturity lines, may put earlier lines at a disadvantage because of increased lodging and shattering losses, and seed damage. The yields and quality of later lines may be depressed because the lines were harvested when immature (McAlister, 1943; Oelke

et al., 1969; Dodds and Warder, 1970).

2. Seed mixing

Seed mixing is a problem commonly associated with combine harvesting. When straight combining methods are used in yield trials separate seed plots are generally necessary to maintain the purity of seedstocks.

3. Adjusting machine settings

Most combines available do not lend themselves to rapid adjustments of the threshing cylinders and the cleaning apparatus, although it is desirable to make such adjustments before harvesting each new line if accurate yield assessments are to be made. Those lines best adapted to the combine settings employed will be favored under circumstances of a constant combine setting.

4. Shattering and lodging losses

Shattering and lodging losses may be very high in poorly adapted material that is allowed to stand until harvest ripeness. This factor may have a detrimental effect on selection made from yield trials.

5. Delaying harvesting operations

Harvesting operations must be delayed until the crop has dried to low moisture contents. Therefore straight combining is best suited to long season climates with favorable ripening conditions.

6. Damaging kernels

Straight combining wet grain or very dry grain may cause kernel damage. Wet kernels may be compressed or broken, and very dry kernels may crack or break during threshing operations (Caldwell and Davies, 1957; Kulik, 1973).. Damaged kernels are more susceptible to attack by storage fungi and bacteria (Caldwell and Davies, 1957; Kulik,

1973), reduced germination (Webster and Dexter, 1961; Jorgensen, 1974; Febles, 1975) and low test weights (Yamazaki and Briggle, 1969).

From the above discussion, it can be concluded that swathing procedures are best suited to short season climates, and, therefore, well adapted to harvesting in northern and central Alberta. The climate of this area is characterized by cooling temperatures and rainfall during the primary harvesting months, August and September. This cooling trend tends to emphasize differences in maturities among cultivars, making the late cultivars extremely late (Briggs, 1976). The harvesting period is corresponding extended. Swathing procedures, because of their flexibility in handling materials of different maturities is best suited to these areas of Alberta. However, the advantages of straight combining of reduced labor and reduced labor costs assume increasing importance as the size of breeding programs increase and as the cost of labor escalates.

In any discussion of harvesting techniques and of early harvesting operations, some consideration must be given to the effect of such operations on the yield and quality of the harvested product. This consideration applies to both swathing and straight combining methods. There is some concern that early harvesting may adversely affect yields. If some portion of the crop is harvested prior to the final deposition of dry matter, yields will be suboptimal. Since dry matter accumulation ceases at physiological maturity, crops may be harvested at this time with no loss in yield (Dodds, 1957, 1967; Molberg, 1963; Koenig et al., 1965; Dodds and Dew, 1958; TeKrony, 1976). There are of course other factors influencing final yield that will determine the optimal time of harvest. Grain at physiological maturity

is damp and the straw very tough. Such grain is difficult to thresh and clean. Machine losses and mechanical damage of the kernels can be considerable when threshing wet grain. Another consideration is that many cultivars tend to shatter and lodge as they ripen. These factors may be emphasized by adverse weather conditions such as strong winds, heavy rain or hail. Thus seed losses of specific lines can be large if harvesting operations are delayed. Mechanical damage of kernels increases slightly at lower moisture contents (Dodds, 1974). Such damage may also contribute to yield losses and losses in quality or grade. The decision as to when to harvest is a complex one that must be tempered by practical considerations such as weather conditions, machinery capacity and length of season remaining (Audsley and Boyce, 1974). For cereal nursery trials, harvesting operations are further complicated by a wide range of maturities in the plant material and the need for accurate , reliable yield estimates.

The final quality of a cereal crop may also be influenced by the timing of harvest. As suggested above, under the discussion of kernel development, metabolism in the kernels may continue beyond physiological maturity. Thus, although yield may not be reduced by harvesting at physiological maturity, quality may be affected. Barley malting quality is suboptimal at physiological maturity and most authors suggest the harvesting of malting barley be delayed until 25-30%mcwb (Dew and Bendelow, 1963; Koenig et al., 1965; Dodds, 1967; Pomeranz et al., 1971). The effects of early harvest on wheat quality are equivocal. Some authors suggest that harvesting at physiological maturity has no detrimental effect on quality (Yamazaki, 1976; Scott et al., 1957). Others report improved sedimentation and baking test results in fully mature wheat (Spillane, 1973). Associated with early

harvesting is the need for artificial drying. If drying is not carried out at proper temperatures, quality can be destroyed (Finney et al., 1962). Early harvest may depress the germination capabilities of a crop either directly (Harlan and Pope, 1923, 1926: Oelke et al., 1969; Wellington, 1956); or, indirectly, through artificial drying effects (Dodds and Warder, 1969) or through fungal and pest infestation (Caldwell and Davies, 1957; Smith, 1973; Wallace and Sinha, 1962; Jorgensen, 1974). Test weights may be adversely affected by early harvest. Low test weights have been reported in cereals harvested at physiological maturity (Koenig et al., 1965; Pomeranz et al., 1971). Others workers have not found similar reductions in test weights with early harvest (Dodds, 1957, 1967; Dodds and Dew, 1958; TeKrony, 1976). Quality characters such as malting quality in barley, bread-making quality in wheat, germination ability, and test weight may all be adversely affected by early harvesting procedures. Several factors must influence decisions concerning when to harvest and subsequent decisions relating to the selection of lines for advancement.

III. Maturity Assessments

An accurate assessment of maturity can be important in several aspects of a cereal breeding program. Programs concerned with developing early cultivars adapted to short growing seasons are dependent upon accurate reliable determinations of maturity if selection for earliness is to be effective. A second major use of maturity assessments is in conjunction with harvesting operations. To correctly

ascertain yielding ability and some quality parameters, experimental cereal lines must be harvested at an optimal maturity. Harvesting a line either too early or too late may have a detrimental effect upon both yield and quality. Thus measures of maturity may influence the selection of experimental lines both directly, as in the selection of early types, and indirectly, through selection for high yield and a specific quality.

Frequently observed landmarks in kernel development are physiological maturity and harvest ripeness. For most cereal crops physiological maturity occurs at about 35-45% mcwb (Harlan, 1920; Aldrich, 1943; Meredith and Jenkins, 1975; Lee et al., 1977). Physiological maturity is considered that point at which dry matter accumulation ceases and desiccation initiates (Harlan, 1920; Harlan and Pope, 1923; Meredith and Jenkins, 1975; Lee et al., 1977). It has been widely demonstrated that cereal crops may be harvested at physiological maturity with no loss in yield (Dodds, 1957, 1967; Dodds and Dew, 1958; Dodds and Warder, 1970). Unlike yield, however, the quality of some cereals may not be fixed at physiological maturity; further alterations in the nature of the reserve materials may occur (Woodman and Engledow, 1924; Dew and Bendelow, 1963; Koenig et al., 1965; Pomeranz et al., 1971; Jenkins et al., 1975). Therefore, harvest at physiological maturity may influence quality. Harvest ripeness is the second landmark of maturity in cereal crops. At harvest ripeness, the drying process is considered completed and the kernels equilibrate with atmospheric moisture content at about 15%mcwb. Most straight combining harvesting operations begin when the crop has reached harvest ripeness. Thus, it is in relation to these two signposts of maturity, physiological maturity and harvest ripeness, that most lines are selected for earliness and that

harvesting operations are conducted.

Percent moisture content is the most common measure of maturity. Alternate measures generally relate in some manner to percent moisture content. Percent moisture content has been correlated with various physical states of development. Visual assessment of maturity based upon dryness of ear husks in maize (Aldrich, 1943), color of the panicle in kentucky bluegrass (Sumner and Lindsay, 1962), color of the panicle in oats (Lee et al., 1977), or late dough stage of kernel development (Harlan, 1920) are a few examples. The primary advantage offered by any such visual determinations of maturity is the ease and rapidity with which a large number of experimental lines may be sampled. Other methods of determining maturity have been proposed. Aldrich (1943) and more recently Lee et al. (1977) have suggested that maximum grain development, although not a practical measure, is a more reliable estimate of maturity than percent moisture content. Daynard and Duncan (1969) stated that the appearance of the black layer at the base of maize kernels was a superior measure of maturity. Formation of the black layer coincided with the death and suberization of the vascular connections between the kernel and the plant. The authors found this measure of maturity facile, rapid and reliable. Lee et al. (1977), working in oats, have developed a method of measuring maturity based upon the cessation of translocation of assimilate to the kernel, using dye uptake in the glumes. Of all the methods proposed for estimating maturity, percent moisture content or moisture content based assessments are the most widely applied.

Any discussion of selection on the basis of maturity in cereal breeding programs must assume some understanding of the nature of the drying process. Several authors have considered aspects of the

drying or ripening process in relation to selection for earliness. Gunn and Christensen (1965) studied the rates of drying in several maize hybrids and concluded that the drying rates were very similar for all hybrid lines tested. The two authors suggested that early silking was therefore a better criteria for selection of early types than a fast rate of drying. In another approach to the problem of selecting early maize lines, Troyer and Ambrose (1971) studied several plant characteristics influencing the drying rates of ear maize. These authors reported that fast drying types, and, therefore early types, may be selected using four plant characters. These characters are loose husks at harvest time, husks the same length as ears, narrow husks of light texture, and low number of nodes, and therefore a low number of husks.

Work of a similar, though less detailed nature, can be found for wheat and barley. Hyde (1971) studied the drying curves of winter wheat cultivars for several seasons. She concluded that the rate of drying was basically linear, and also, fairly consistent over all growing seasons. The regularity of the drying curves suggested to Hyde their usefulness for predictive purposes. McKelvie (1968), based upon similar studies of drying curves of barley in Scotland, made a similar observation as to the predictive value of drying curves. The Scottish author made several additional interesting comments concerning the nature of drying curves in barley. That the influence of the climate differs from the effect of local weather conditions on drying curves was one important point the author emphasized. McKelvie (1968) demonstrated that the rate of drying varied according to the potential transpiration associated with the farming district. This association was valid for a large number of sites ranging over the full length of Scotland. In

contrast, the author stated that the local weather conditions, rainfall in particular, had little or no effect upon the drying rates associated with a particular area. Moisture added to the kernel as rainfall was considered by McKelvie (1968) to be superficial moisture that was lost rapidly. The moisture content of a wetted kernel returned to a moisture content similar to that which it would have attained under conditions of no rainfall. The rate of drying as envisioned by McKelvie (1968) is governed by the loss of metabolic moisture in an active physiologic process.

Meredith and Jenkins (1975) consolidated the ideas of McKelvie (1968) and others in a model of the drying process. Initial studies by these researchers confirmed that the decline in the proportion of grain moisture as kernel development progressed represented both apparent and real losses of moisture from the kernels. They found, however, that rates of drying (loss of moisture content expressed on a dry weight basis per unit time) were linear over a large portion of kernel development. Drying curves of the winter wheat cultivar Cappelle-Desprez were noteable in this respect. These results prompted the authors to conduct a survey of the literature for additional examples of drying curves of cereal crops. In their paper, Meredith and Jenkins (1975), illustrated the drying curves of several cultivars of wheat, barley and oats taken from several parts of the world. In each case, the rate of drying appeared fairly constant over the course of development. The deviations from the basic drying rate related to local weather conditions.

The model Meredith and Jenkins (1975) proposed was derived from these drying curves. The authors suggested that two pools of moisture exist in the kernel: one pool consists of metabolic moisture,

and the second pool is superfical moisture added by rainfall or condensation. Further, the authors proposed that the metabolic moisture is removed from the kernel by an active physiological process common to most cereal crops. Superficial moisture is removed passively by evaporation. The authors outlined several alternate hypotheses to explain the drying process based on the number of pools of moisture (one versus two) and on the nature of the drying mechanism (active versus passive). Only the first model was supported by published data.

The implications of the Meredith and Jenkins model are twofold. The model predicts that little or no variation exists among genotypes or even among common crop species for the rate of drying. Thus, little sucess can be expected in the selection of early lines by choosing fast drying types in cereal breeding programs. The research of Gunn and Christensen (1965) in maize, affirms this prediction. The model also implies that local weather disturbances do not significantly influence the drying rate. Evaporation of added moisture returns the percent moisture content to a value consistent with the inherent drying rate.

Local weather and certain plant characteristics may affect the addition and removal of superficial moisture. Such factors as precipitation and condensation may contribute moisture to the kernel, thereby raising the moisture content. Evaporation of this moisture may be governed by relative humidity, temperature, radiation or air movement. Several researchers have discussed the relationships between fluctuations from the basic drying curves and various weather parameters. McKelvie (1968) and Hyde (1971) reported that rainfall added moisture to the kernels, resulting in increased moisture contents. Subsequent to the period of rainfall, the added moisture was lost by evaporation. Dodds

and Pelton (1967) undertook a more detailed comparison of the fluctuations from the drying curves of a spring wheat cultivar, Chinook, and fluctuations in several weather parameters. Rainfall, soil moisture and condensation appeared to contribute to deviations from the drying curve. The authors considered the parameter, vapor pressure deficit, as the most descriptive of the fluctuations about the drying curves. Plant characteristics, such as permeability of the pericarp (MacMasters et al., 1964) or the nature of the husks of ear maize (Troyer and Ambrose, 1971) may influence addition and loss of superficial moisture. This result suggested that the decline in percent moisture in cereal kernels was at a constant rate dependent upon active physiological processes (adding dry matter and removing metabolic water). Local daily weather has no influence on the basic drying rate but may cause fluctuations in the rate of drying by transiently adding moisture in the form of rainfall or condensation (McKelvie, 1968; Hyde, 1971; Meredith and Jenkins, 1975).

In conclusion, maturity assessments are an integral part of cereal breeding programs. Their influence extends to the selection of maturity types and to the harvest operations. Percent moisture content is the most widely employed measure of maturity. Assessments of maturity based upon the proportion of moisture may be confounded by superficial moisture added by precipitation or condensation. Superficial moisture added by rainfall may also delay harvesting operations until removed by evaporation.

MATERIALS AND METHODS

I. Location and Season

The University of Alberta Research Farm at Ellerslie was the site of the experiments described herein. The soil type of this location is Malmo Clay loam. The growing season during 1976, the year of these experiments, was unusual in two respects. The spring season was considered dry. Also the growing season was very long - 151 frost-free days. The long term average for the Ellerslie research station is 109 frost-free days (Attinaw, 1977; table 1).

II. Harvesting Methodology

A. Experimental Design

Two harvesting methodology tests were grown, one for wheat and one for barley. The experimental design used for both tests was a split-plot design with cultivars as main plots and harvesting treatments as subplots.

B. Plant Material

1. Wheat

For the harvesting methodology test in wheat, five spring wheat (Triticum aestivum L. em Thell) cultivars were used. They were Park, Neepawa, Norquay, Glenlea and Pitic 62. In addition, two

Table: 1 Meteorological Data for Ellerslie Station - 1976 and Long Term Averages[1]

Month	Mean Maximum Temperature (°C)		Mean Minimum Temperature (°C)		Precipitation (mm)	
	1976	Long Term[2] Average	1976	Long Term[2] Average	1976	Long Term[2] Average
May	19.4	17.6	4.4	3.7	18.7	19.8
June	19.0	20.5	6.6	7.6	101.9	43.8
July	22.7	22.3	9.7	9.6	69.9	39.2
August	22.6	21.5[3]	11.2	8.8[3]	78.1	35.6
September	19.5	16.0	5.7	3.7	44.0	35.8

1976: number of frost-free days - 151 days
Long Term Average: number of frost-free days - 109 days (Attinaw, 1977)

1 from Division of Meteorology, Department of Geography, University of Alberta

2 based on 13 years data

3 based on 14 years data

experimental lines, 70M009002 and 70M110001, from the Utility Wheat Breeding program of Dr. K.G. Briggs were used. The seven genotypes chosen represent a broad range of types and maturities. A detailed description of these cultivars and lines may be found in table 2.

2. Barley

In the barley harvesting methodology test, six six-row, spring barley (Hordeum vulgare) cultivars were used - Olli, Gateway 63, Conquest, Bonanza, Galt and Jubilee. Table 3 contains a description of these genotypes. As with the wheat test, these cultivars were chosen because they were standard, well characterized types, exhibiting a wide range of maturities and types.

C. Treatments

Planting and maintenance of the field plots for both tests followed standard procedures developed for yield trials. The two tests were seeded May 7, 1976 to fallow land that had been fertilized the previous fall (18.7 kg/ha nitrogen, 40.9 kg/ha phosphorous, 0 kg/ha potassium) according to soil test recommendations. The tests were seeded 100 kg/ha for wheat and 80 kg/ha for barley, using a four row experimental plot seeder developed at the Canada Department of Agriculture Research Station at Swift Current. Standard row spacing and row length for yield tests of 23 cm and 6.1 m respectively were used. After seeding the mainplots were subdivided into subplots for harvest treatments. There were ten harvest treatments in the wheat test and three in the barley test. Provision was made to swath and thresh one plot for every genotype in each block at the date of physiological maturity for each genotype; however in three instances, two cultivars attained physiological

Table: 2 General Characteristics of Seven Wheat Genotypes

Genotype	Origin	Year Licensed in Canada	Canadian Market Class	Relative[1] Maturity (days from seeding)	Yield[1] (% of Neepawa)	Height[1] (cm)	Seed[1] Weight (g/1000 k)	Test[1] Weight (kg/hl)	Lodging[2] Resistance	Shattering[2] Resistance
Park	Alberta	1963	Hard Red Spring	112	87	93	34.8	81.8	good	good
Neepawa	Manitoba	1961	Hard Red Spring	114	100	94	35.7	81.5	good	good
Norquay	Manitoba	1975[3]	Utility	117	105	74	39.7	80.7	good	good
Glenlea	Manitoba	1972	Utility	120	102	100	44.8	81.5	good	good
Pitic 62	Mexico	1969	Utility	127	117	82	36.7	79.2	fair	fair
70M009002[4]	Mexico	--	Utility	113	92	71	38.5	81.8	--	--
70M110001[5]	Mexico	--	Utility	116	104	73	38.7	81.2	--	--

1 Attinaw (1977)

2 Alberta Cereal and Oilseed Advisory Committee (1977)

3 delicensed in 1976

4 70M009002 = CIANO S x ((SON 64-Y 50ES x G10) INIA 'S')

5 70M110001 = CIANO S x ((CIANO x SON-KL. Rend) 8156)

Table: 3 General Characteristics of Six Barley Genotypes

Genotype	Origin	Year Licensed in Canada	Canadian Market Class	Relative[1] Maturity (days from seeding)	Yield[2] (% of Galt)	Height[1] (cm)	Seed[1] Weight (g/1000 k)	Test[1] Weight (kg/hl)	Lodging[2] Resistance	Shattering[2] Resistance
Olli	Ontario	1935	Malting	90	74	87	33	47	poor	poor
Gateway 63	Alberta	1963	Malting	94	80	90	33	48	fair	fair
Conquest	Manitoba	1965	Malting	95	89	108	38	50	good	fair
Bonanza	Manitoba	1970	Malting	98	97	100	36	49	good	fair
Galt	Alberta	1966	Feed	101	100	90	36	50	good	good
Jubilee	Saskatchewan	1960	Feed	103	96	87	36	49	fair	fair

1 Hamid (1977)

2 Alberta Cereal and Oilseed Advisory Committee (1977)

maturity at the same time, thereby reducing the number of "swath and thresh" harvesting treatments from nine to six and the number of total harvesting treatments from thirteen to ten in the wheat test.

Herbicide in the form of MCPA-K was applied June 1 at the four to five leaf stage to control broad leaf weeds such as hemp nettle. Further weeding and rogueing was done by hand during the growing season. Prior to the initial harvest treatment, end borders were removed from all plots (August 6). The final row length at harvest was 5.0 m.

1. Wheat

The ten harvesting treatments employed in the wheat harvesting methodology test are described below. See table 4 for a list of the harvest treatments.

a. Treatment 1 - Conventional System

Prior to harvest, a sample of ten heads was gathered and stored on ice until threshed. Initially threshing was done by hand, but later in the season, threshing was done mechanically. Moisture contents were determined on the resulting samples using the air-oven method (A.A.C.C., 1962).

The center two rows of a four row plot were harvested with a two-row plot harvester (harvested area: 2.3 m^2). The swath, including the straw and grain, was collected, bagged in cloth sacks, and allowed to dry on racks. The swath was dried 36 - 48 hours at about 32°C in grain driers prior to threshing with a stationary Vogel thresher. This method of handling the grain at harvest was intended to mimic the windrowing method of harvest commonly employed

Table: 4 Days from Seeding and Moisture Content of Seven Wheat Genotypes for Ten Harvesting Treatments

Genotype	Harvest Treatment																			
	1		2		3		4		5		6		7		8,9		10			
	Days from Seeding	%mcwb[1]	Days from Seeding	%mcwb	Days from Seeding	%mcwb	Days from Seeding	%mcwb	Days from Seeding	%mcwb	Days from Seeding	%mcwb	Days from Seeding	%mcwb	Days from Seeding	%mcwb	Days from Seeding	%mcwb		
Park	108	27.991	103	36.917	108	27.991	112	31.814	110	22.256	115	19.106	123	27.370	117	19.144	141	16.838		
Neepawa	112	35.578	103	42.191	108	33.249	112	35.578	110	31.508	115	21.377	123	28.070	117	17.662	141	16.699		
Norquay	110	30.698	103	41.379	108	33.415	112	34.987	110	30.698	115	20.163	123	28.812	117	18.317	141	17.754		
Glenlea	115	31.084	103	44.551	108	40.137	112	40.160	110	37.726	115	31.084	123	28.915	117	24.345	141	16.904		
Pitic 62	115	28.811	103	45.784	108	40.820	112	39.652	110	39.550	115	28.811	123	28.914	117	24.872	141	16.332		
70M009002	110	29.592	103	40.093	108	31.202	112	34.704	110	29.592	115	22.538	123	27.669	117	20.458	141	16.376		
70M110001	108	32.699	103	40.587	108	32.699	112	34.381	110	31.021	115	24.282	123	29.017	117	19.948	141	16.384		

1 moisture content - wet basis

by farmers in central and northern Alberta. After threshing, the grain was weighed, recleaned, and reweighed. The percent moisture content of the dry grain samples was determined using a Burrows moisture meter. Finally, the grain was stored for further measurements.

b. Treatment 2 - Swath and Thresh One Week Prior to the Date of Physiological Maturity of the Earliest Genotype

The "swath and thresh" treatments were designed to simulate once-over straight combining in cereal trials.

Treatment 2 was introduced to test the effects of premature harvest. The attempt to harvest one week prior to physiological maturity of the earliest genotype, Park, was unsuccessful (table 4); however, this harvest treatment is still representative of a premature harvest.

Prior to harvest, a sample of heads was gathered, and later threshed for moisture content determinations (A.A.C.C., 1962). The center two rows of a four row plot were cut with a plot harvester (harvested area: 2.3 m^2). The swath was collected and threshed immediately with a stationary Vogel thresher. The grain weight was determined (wet weight). The grain was then dried at 32°C until safe for storage. A "dry weight" measurement was made, the grain recleaned, and a second dry weight taken (dry weight of cleaned grain). Before storage, moisture content (Burrows) was measured on the clean, dry grain.

c. Treatment 3 - Swath and Thresh at the Physiological Maturity of Park and 70M110001

as described for treatment 2

d. Treatment 4 - Swath and Thresh at the Physiological Maturity of Neepawa

as described for treatment 2

e. Treatment 5 - Swath and Thresh at the Physiological Maturity of Norquay and 70M009002

as described for treatment 2

f. Treatment 6 - Swath and Thresh at the Physiological Maturity of Glenlea and Pitic 62

as described for treatment 2

g. Treatment 7 - Swath and Thresh One Week After the Physiological Maturity of the Latest Genotype

Treatment 7 was included to test the effects of late harvesting. Although the intent was to harvest one week after the latest gentoype, Pitic 62, attained physiological maturity, in fact, this harvest was made about 10 days after Pitic 62 reached physiological maturity. The procedure used was that described for treatment 2.

h. Treatment 8 - Straight Combining

Prior to harvest, a sample of heads was collected for moisture content determinations (A.A.C.C., 1962). A Hege experimental plot combine was used for harvesting. Once-over harvesting was practiced, whereby, one plot per genotype per block was harvested. The harvest unit was based on an eight row plot; the center six rows were harvested (harvested area: 6.9 m^2). Wet weight measurements of the grain were taken. A 2000 g subsample of wet grain was dried (32°C; 36 - 38 h); and the dry weight and percent moisture content (Burrows) measured on the cleaned grain before storage.

i. Treatment 9 - Straight Combining in Plots with Blank Guard Rows

The outer guard rows were destroyed shortly after seeding (June 13), leaving the six row plots bordered by blank guard rows. This harvest treatment was included so that the effects of an altered plot type could be evaluated. With the exception of plot type, treatment 9 was identical to treatment 8.

j. Treatment 10 - Straight Combining Late in the Season

Treatment 10, straight combining late in the season, was similar to straight combining treatment 8 and 9. The moisture content of the standing grain was assayed using standard procedures (A.A.C.C., 1962). The Hege combine was used to cut and thresh plots. For this treatment, the center three rows of a five row plot were harvested (harvested area: 3.7 m^2). Wet weight measurements were made on the freshly harvested grain. The complete sample was dried, weighed, cleaned, reweighed, and the percent moisture content read on a Burrows meter. The grain was then stored for further measurements.

2. Barley

The three harvesting treatments in the barley test are described below. Table 5 lists the harvest treatments employed.

a. Treatment 1 - Conventional System

The conventional system of harvesting for the barley test involved the harvest of the center two rows of a four row plot (harvested area: 2.3 m^2), at the physiological maturity of a given genotype. Moisture contents were determined on a sample of fifteen heads gathered prior to harvest (A.A.C.C., 1962). The swath was cut with a sickle as most cultivars were severely lodged at the time of

Table: 5 Days from Seeding and Moisture Content of Six Barley Genotypes for Three Harvesting Treatments

Genotype	Harvest Treatment					
	1		2		3	
	Days from Seeding	%mcwb[1]	Days from Seeding	%mcwb	Days from Seeding	%mcwb
Olli	91	37.940	91	37.940	97	21.411
Gateway 63	94	42.548	94	42.548	101	16.956
Conquest	97	29.349	97	29.349	103	25.793
Bonanza	101	21.115	101	21.115	103	27.822
Galt	101	21.309	101	21.309	103	26.254
Jubilee	101	23.319	101	23.319	103	28.416

1 moisture content - wet basis

the time of harvest. The straw with grain was bagged, and hung on racks to dry. Threshing was by means of a stationary Vogel thresher, once the swath had been dried in driers (32°C; 36 - 48 h). The grain was cleaned, and the dry weight and percent moisture content (Burrows) determined. The grain was then stored for future measurements.

b. Treatment 2 - Swath and Thresh at Physiological Maturity

As for the wheat experiment, the swath and thresh harvest treatments in the barley test were intended to simulate straight combining methods.

As each cultivar attained physiological maturity, two plots per block were harvested for that cultivar, one by the conventional system and the other by a swath and thresh method.

Prior to harvest, the percent moisture content of the standing crop was determined (A.A.C.C., 1962). The center two rows of a four row plot were cut with a sickle (harvested area: 2.3 m^2); and the swath was threshed immediately with a stationary Vogel thresher. The grain was cleaned and weighed before drying in driers. Then the grain was reweighed, and the percent moisture content read using a Burrows meter, before storage.

c. Treatment 3 - Swath and Thresh at Harvest Ripeness

Of the three treatments studied in the barley test, harvest treatment 3 most closely resembled straight combining methods.

The procedure used for treatment 3 was identical to that described above for treatment 2, except the cultivars were harvested as they approached harvest ripeness or about 20%mcwb.

D. Characters

1. Wheat

The characters used to ascertain the effects of the various harvesting treatments are described below.

a. Protein Content (%)

The protein content of wheat samples was determined on whole wheat flour using infrared spectral analysis techniques. A 50 g sample of wheat was ground with a Udy mill. The flour was prepared for analysis according to instructions given for the Neotec analyzer, and percent protein values read from a Neotec GC analyzer. The Neotec had been previously calibrated with wheat flour samples of known protein content as determined by standard Kjeldahl techniques.

b. Seed Weight (g/1000 kernels)

i. Seed Weight, values unadjusted for moisture content

One subsample of 200 kernels, counted with a Countapac machine, was weighed in grams on a Mettler scale. This weight was multiplied by a factor of five to give a 1000 kernel weight.

ii. Seed Weight, values adjusted to 10%mcwb

The seed weight values obtained above were adjusted to 10%mcwb using the Burrows moisture reading taken at the same time as the seed weight determinations.

c. Test Weight (kg/hl)

i. Test Weight, values unadjusted for moisture content

The test weight of each sample was determined as g/pint using standard apparatus for this test. Test weight values were then converted to kg/hl.

ii. Test Weight, values adjusted to 10%mcwb

Test weight determinations were recalculated to a 10%mcwb

basis using the Burrows moisture reading taken at the same time as the test weights.

d. Germination (%)

The percent germination of wheat samples was tested according to procedures given by the Official Seed Analysts Association Rules (1970). Duplicate determinations were made for percent germinations. A sample of 100 kernels was spread evenly over the top of a plastic petrie dish (100 mm in diameter), previously lined with two white, Whatman #40 ashless filter papers. Four ml of distilled water were added to the top of the petrie dish. The bottom cover of the petrie dish was used to cover the sample. Petrie dishes were placed on trays (20/tray) in random order, and then stored in a germinator for five days. The temperature was kept constant at 18°C and the cabinet maintained at high humidity. One ml aliquots of distilled water were added to the petrie dishes if the filter papers became dry. Every 24 hours beginning at 48 hours and continuing until 120 hours, the samples were scored for germination. Germination was considered the appearance of a normal coleorhiza and coeloptile. Germinated seeds were counted and removed. Also, any seeds excessively contaminated by bacteria or fungi were removed to counteract the spread of these pathogens to healthy seeds. Several extremely contaminated samples were analyzed by Drs. W. Skoropad and J.P. Tewari of the Plant Pathology division of the University of Alberta.

e. Dockage (%)

Two factors of the harvesting operations made cleaning of the threshed grain samples necessary. One factor was that the wind speed on the Vogel thresher was set at a very low level to ensure that kernels

were not lost during threshing operations. An accurate assessment of yield was considered desirable. The second, and more influential factor necessitating recleaning of the grain samples was the fact that many samples were threshed when the grain was very damp. At moisture contents greater than 25 - 30%mcwb, samples threshed very poorly. Kernels from immature tillers were often compressed or the seed coat broken. Heads were not completely threshed, and frequently, the floral bracts adhered to the kernels. Thus after drying, samples were put through a barley deawner, the abrasive action of this machine removing the floral bracts; and then put over a sieve and fan to remove small, damaged kernels, and to remove straw, chaff and unthreshed heads. This material constituted dockage. Weed seeds and green weed material were not problematic in the threshing and cleaning of samples. Dockage was determined from the difference in weights of the dried and the dried, cleaned samples, and was expressed as a percentage.

f. Yield (g/2.3 m^2)

i. Yield, wet weight of uncleaned grain, value unadjusted for moisture content (WSU)

This yield parameter was obtained by measuring the weight of grain in grams after the threshing operation, and prior to either cleaning or drying. This weight and all other yield weights were determined using a Mettler scale. The yield so obtained was left uncorrected for the moisture content of the grain sample. For treatment 1, this wet weight measure was calculated from the moisture content at harvest and the dry weight of uncleaned grain adjusted to 10%mcwb (DSA). The wet weights of treatments 8, 9, and 10 were calculated on a two row plot basis for comparison with the remaining seven treatments.

ii. Yield, wet weight of uncleaned grain, value adjusted to 35%mcwb (WSA)

This measure of yield was calculated from the above (WSU) yield measure and the moisture content at harvest. For treatments 8, 9, and 10 these values were adjusted to a two row plot basis.

iii. Yield, wet weight of cleaned grain, value unadjusted for moisture content (WCU)

The wet weight of cleaned grain, unadjusted for moisture content was derived from the dry weight of cleaned grain, adjusted to 10%mcwb (DCA) and the percent moisture content of the standing crop at harvest. Treatments 8, 9, and 10 yield values were adjusted to a two row plot basis.

iv. Yield, wet weight of cleaned grain, value adjusted to 35%mcwb (WCA)

This wet weight yield measure was obtained from the dry weight of cleaned grain value adjusted to 10%mcwb (DCA). Treatments 8, 9, and 10 were calculated on a two row plot basis.

v. Yield, dry weight of uncleaned grain, value unadjusted for moisture content (DSU)

The weight of grain, in grams, immediately after drying was used for this measure. For treatments 8, 9, and 10 values were converted to a two row plot basis.

vi. Yield, dry weight of uncleaned grain, value adjusted to 10%mcwb (DSA)

A Burrows moisture determination and the above dry weight measure (DSU) were used to determine this yield measure. Treatments 8, 9, and 10 were corrected to a two row plot basis.

vii. Yield, dry weight of cleaned grain, value unadjusted for moisture content (DCU)

Once the dried grain had been cleaned, the sample was reweighed. This value was used for the yield parameter dry weight of cleaned grain, value unadjusted for moisture content. Adjustments were made for the subsampling in treatments 8 and 9, and the yields of the last three treatments were converted to a two row plot basis.

viii. Yield, dry weight of cleaned grain, value adjusted to 10%mcwb (DCA)

This yield parameter was derived from the previous measure of yield (DSU) and the Burrows moisture reading of dried, cleaned grain.

g. Moisture Content at Harvest (%mcwb)

The percent moisture content at harvest was determined in conjunction with each harvest. Samples of heads were gathered immediately prior to harvest, and threshed as described on page 36. Moisture contents of the samples were measured using the air-oven method (A.A.C.C., 1962).

h. Moisture Content of Dry Grain (%mcwb)

A Burrows moisture meter was utilized for these moisture determinations. This machine uses the dielectric properties of the grain to determine the percent moisture content. The readings are sensitive to the volume of grain and its packing. Therefore measurements were made on clean grain only, with the awns and chaff removed. Also, the meter is accurate over a range of low moisture contents (less than 25%mcwb), and was therefore used only with dried grain.

i. Moisture Content of Grain after Storage (%mcwb)

These moisture determinations were made in conjunction with

the test weight and seed weight measurements. Again, the Burrows moisture meter was used to test the wheat samples.

j. Tillering (number of tillers/m)

Tillers counts were recorded as the total number of tillers in a one meter length. Tiller counts were taken in eight rows per main plot. Four rows were chosen at random as controls, and the remaining four rows were those rows adjacent to the two blank guard rows of treatment 9.

2. Barley

The characters measured for the barley harvesting methodology test were as follows.

a. Protein Content (%)

The method used to determine protein content of the barley sample was the same as that described in the wheat experiment. Two readings were taken for each sample and their mean used as the protein content value. The barley samples seemed inherently more variable than the wheat samples when used in the Neotec. The smaller proportion of endosperm and the greater proportion of fibrous material in whole barley flour as a result of the inclusion of the hulls may have accounted for the greater variability of the barley samples. It is for this reason that two readings were taken for every barley sample.

b. Seed Weight (g/1000 kernels)

i. Seed Weight, value unadjusted for moisture content as described for wheat

ii. Seed Weight, value adjusted to 10%mcwb as described for wheat

c. Test Weight (kg/hl)

i. Test Weight, value unadjusted for moisture content as described for wheat

ii. Test Weight, value adjusted to 10%mcwb as described for wheat

d. Germination (%), e. Germination Resistance, and f. Uniformity Factor

The characters germination, germination resistance and uniformity factor are different measures of the process of germination. Therefore a single set of germination tests were conducted, from which all three germination characters were determined. The germination procedure used for the barley samples closely resembled that developed by Gordon (1971). Sterile techniques were introduced to reduce fungal and bacterial contamination. Germination was scored as the appearance of the coleorhiza (Gordon, 1971). Germinated seeds were counted and removed every 12 hours for five days. Duplicate germination tests were carried out on each barley sample. The barley germination tests were made after the grain had been held in storage for six months and seed dormancy was not encountered in any of the samples tested, as evidenced by the high percent germination values observed.

The character percent germination was calculated as the proportion of seeds germinating, and converted to a percentage value. The germination resistance (GR) and uniformity factor (UF) values were calculated using the formulae given below (Gordon, 1971).

$$GR = \frac{\frac{t_1}{2}(n_1) + \frac{t_2+t_1}{2}(n_2-n_1) + \ldots + \frac{t_i+t_{i-1}}{2}(n_i-n_{i-1})}{n_i}$$

$$UF = \sqrt{\frac{[GR-\frac{t}{2}1]^2 n_i + [GR-\frac{t_2+t}{2}1]^2 + \ldots + [GR-\frac{t_i+t}{2}i-1]^2 (n_i-n_{i-1})}{n_{i-1}}}$$

t_i = i^{th} hour of test

n_i = total number of grains germinating by t_i time

g. Yield (g/2.3 m^2)

i. Yield, wet weight, value unadjusted for moisture content (WU)

After threshing and cleaning, the weight of grain was measured in grams on a Mettler scale. This weight was used as the wet weight, unadjusted to a constant moisture. The nature of treatment 1 prevented wet weight determinations so they were derived from dry weight (DA) measures and the moisture content of the standing crop at harvest.

ii. Yield, wet weight, value adjusted to 35%mcwb (WA)

Using the above wet weight value and the percent moisture content of the standing crop at harvest values, the second wet weight yield parameter was calculated.

iii. Yield, dry weight, value unadjusted for moisture content (DU)

Grain weight after drying was read from a Mettler scale in grams. This value represented the dry weight, unadjusted for moisture content.

iv. Yield, dry weight, value adjusted to 10%mcwb (DA)

This yield measure was derived from the previous dry weight determination (DU) and the Burrows reading of percent moisture content of the dried grain.

h. Moisture Content at Harvest (%mcwb)

as described for wheat

i. Moisture Content of Dried Grain (%mcwb)

as described for wheat

j. Moisture Content of Grain after Storage (%mcwb)

as described for wheat

E. Statistical Analysis

Analysis of variance was the principle method of analysis used for the two harvesting methodology tests. The analysis of variance design was designed to accommodate a split-plot field design. The harvesting treatment means and genotype means were compared using Duncan's Multiple Range test.

Significant genotype x harvest treatment interaction effects were studied in detail. Such interaction effects were thought to influence assessment of the genotypes under alternate harvest regimes. Analysis of variance for each harvest treatment was performed and the genotype means within each treatment compared using Duncan's Multiple Range test. The relative performances of the genotypes under each harvest regime were compared using simple correlations between each of the alternate harvest treatments and the control or conventional harvest treatment.

Significant interaction effects of genotypes with moisture adjustment for the characters seed weight and test weight and of genotype with measure of yield were analyzed in a similar manner to genotype x treatment interaction effects. Simple correlations calculated during the study of higher order interactions were tested for homogeneity before

combining for study of lower order interactions (Snedecor, 1973).

It should be noted that missing plot values for percent moisture content at harvest for Olli barley in block 3, and dry weight of uncleaned grain for wheat cultivar, Glenlea, in harvest treatment 5, block 3 were calculated according to methods outlined by Anderson (1943).

III. Maturity Assessments

A. Experimental Design

The two maturity assessment experiments, one in wheat and one in barley, were conducted in the plots used for the harvesting methodology tests. A randomized complete block design, with four replicates was the experimental design used for these tests. The seven wheat and six barley genotypes took the place of treatments in this design.

B. Maturity Determinations

1. Wheat

a. Days from Seeding to 35%mcwb

The date a genotype attained 35%mcwb was determined from the drying curves constructed for each genotype as described below. This measure was then converted to number of days from seeding.

b. Days from Seeding to Heading

Number of days from seeding to heading is a visual method

of assessing maturity. This measure was expressed as the number of days from seeding to when the heads have fully emerged from the boot in 75% of the plot.

c. Field Rating (1 - 9)

Dr. K.G. Briggs visually assessed plots for relative maturity and assigned them a relative maturity score (August 13). Those genotypes scored as 9 were considered very early, and those which received a 1 rating were very late. This rating was carried out about one week before the initial harvests.

d. Delmhorst G-6c Reading (%mcwb)

Dr. K.G. Briggs sampled each genotype for moisture content using the Delmhorst G-6c moisture meter (August 14). These measures were taken shortly before harvesting began, and were used as indicators of relative maturity of the genotypes.

e. Days from Seeding to Swathing Ripeness

This measure of relative maturity is also a visual method of maturity determination. It was made by Mr. K. Kutschera, technician in charge of cereal research, and was recorded as the number of days from seeding to when kernels had reached the late dough stage of development (the plot is considered ready to swath).

2. Barley

a. Days from Seeding to 35%mcwb

as described for wheat

b. Days from Seeding to Heading

as described for wheat

c. Field Rating (1 - 9) (August 5)

as described for wheat

d. Delmhorst G-6c Reading (%mcwb) (August 9)

as described for wheat

e. Days from Seeding to Swathing Ripeness

as described for wheat

C. Moisture Determinations

1. Wheat

a. Standard Air-Oven Moisture Determination

Sampling began three to four weeks after heading, at which time the moisture content of the cultivars ranged from 65 -75%mcwb. Samples were taken every two to three days, weather permitting, until very late in the growing season. All cultivars had reached a moisture content of about 15%mcwb. Appendix 1 contains the sampling dates and moisture contents of the genotypes at these dates. Sampling was done between 8:30 and 9:30 in the morning of each sampling date. Samples were gathered according to the method described on page 36, and moisture contents were determined using the American Association of Ceral Chemists air-oven method (1962). Moisture content values were calculated on both a wet and a dry weight basis.

b. Delmhorst G-6c Reading

In addition to the standard moisture determinations, moisture content of undried kernels was also measured with a Delmhorst G-6c moisture meter. The Delmhorst G-6c meter assesses the moisture content of samples based upon their dielectric properties. The advantages of this meter relate to its smallness. It is readily portable and can be used in the fields. Only a small sample of grain is required for the moisture content determination (the grain from one to three heads).

Therefore the Delmhorst G-6c meter was assessed for accuracy and applicability to field plot testing.

Operation of the Delmhorst G-6c moisture meter was according to instructions supplied by the manufacturer. Approximately five grams of threshed grain were placed in a single layer covering the bottom of the measuring dish, and then moisture content readings were taken. Adjustment of the moisture content values for the temperature of the samples was made using the supplied conversion chart.

Grain gathered for the standard air-oven determinations was subsampled periodically for Delmhorst G-6c measurements. Thus for several sampling dates, the Delmhorst G-6c values could be compared to those obtained by standard methods to test the accuracy of the moisture meter.

2. Barley

a. Standard Air-Oven Moisture Determination

For barley, sampling for moisture content evaluation by standard techniques began three to four weeks after heading. The moisture content of the six cultivars at the beginning of the maturity assessment experiment ranged from 50 - 60%mcwb. As in the comparable wheat test, samples were taken every two to three days, weather permitting, until late in the growing season. Fifteen heads were sampled per plot in the barley test. Dates of sampling and moisture contents of the barley genotypes are given in Appendix 2.

The assay technique used was that of the American Association of Cereal Chemists (1962), and was identical to the procedure described for wheat.

b. Delmhorst G-6c Reading

as described for wheat

D. Weather Parameters

Daily weather records for the 1976 growing season, from the Ellerslie Meteorological Station were obtained from the Department of Geography - Meteorological Division, University of Alberta. The meteorological station was located about one km from the test site. These records were analyzed in conjunction with the standard moisture determinations, in an attempt to relate the drying process in cereal grains to various weather parameters. The weather parameters employed for this aspect of the study were as follows.

1. degree growing days (°C) - number of degrees the mean daily temperature exceeded the base line temperature of 5°C
2. maximum temperature (°C)
3. minimum temperature (°C)
4. grass level minimum temperature (°C)
5. dew point (°C)
6. relative humidity (%)
7. precipitation (mm)
8. daily wind run (miles)
9. accumulated wind run (miles)
10. maximum daily wind speed (miles/h)
11. minimum daily wind speed (miles/h)
12. evaporation (inches of water added or removed)
13. cloud cover (1=cloudy, and 0=sunny)

14. daily solar radiation (langley)

15. hours of bright sunshine

E. Statistical Analysis

1. Maturity Determinations

For the wheat and barley experiments, analysis of variance and Duncan's Multiple Range test were used to detect significant differences among the genotypes for maturity for each of the five different maturity determinations. Simple correlations were used to compare the various methods of assessing maturity.

In addition, the accuracy and reliability of the Delmhorst G-6c meter was tested by comparing the meter values with standard air-oven values using the t-test and simple correlation.

2. Drying Curves

Drying curves for each of the genotypes from both tests were constructed from the standard air-oven moisture determinations obtained over the course of the growing season. The model proposed by Meredith and Jenkins (1975) provided the basis or working model for the analysis of these curves.

It should be noted here that only three of the four possible block values from the barley test were used. Missing values for Olli in block 3 complicated statistical analysis; therefore, block 3 values for all cultivars were dropped from further analysis.

The first part of the analysis of the drying curves was concerned with describing the basic, inherent drying rate for each

genotype. The least squares method of analysis was used to fit regression curves to the drying curves. Several regression models were examined and compared using the complete data set for wheat and for barley. These models include:

1. Simple Linear Regression

$$Y = b_0 + b_1X + e$$

Y: moisture content
X: days from seeding

2. Polynomial Regression

$$Y = b_0 + b_1X + b_2X^2 + b_3X^3 + \ldots + b_nX^n + e$$

Y: moisture content
X: days from seeding

3. Multiple Regression

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + e$$

Y: moisture content
X_1, X_2, and X_3: dummy variables

The final model, the multiple regression model was used to describe two linear trends and their point of intersection. This approach was developed by Draper and Smith (1966) to estimate linear time trends in economic data. Using this method four variables are defined and can be used to compare the drying process among genotypes for similarities and differences (figure 3). The b_0 coefficient defines the intercept of the first line and represents the "initial" moisture content of a given genotype. The slope of the first line is quantified by the b_1 coefficient. The b_1 regression coefficient describes the rate of drying. The slope of the second line, represented by b_2, can also be thought of as describing a rate of moisture loss. It was expected that the slope of this second line would approximate zero because the grain was

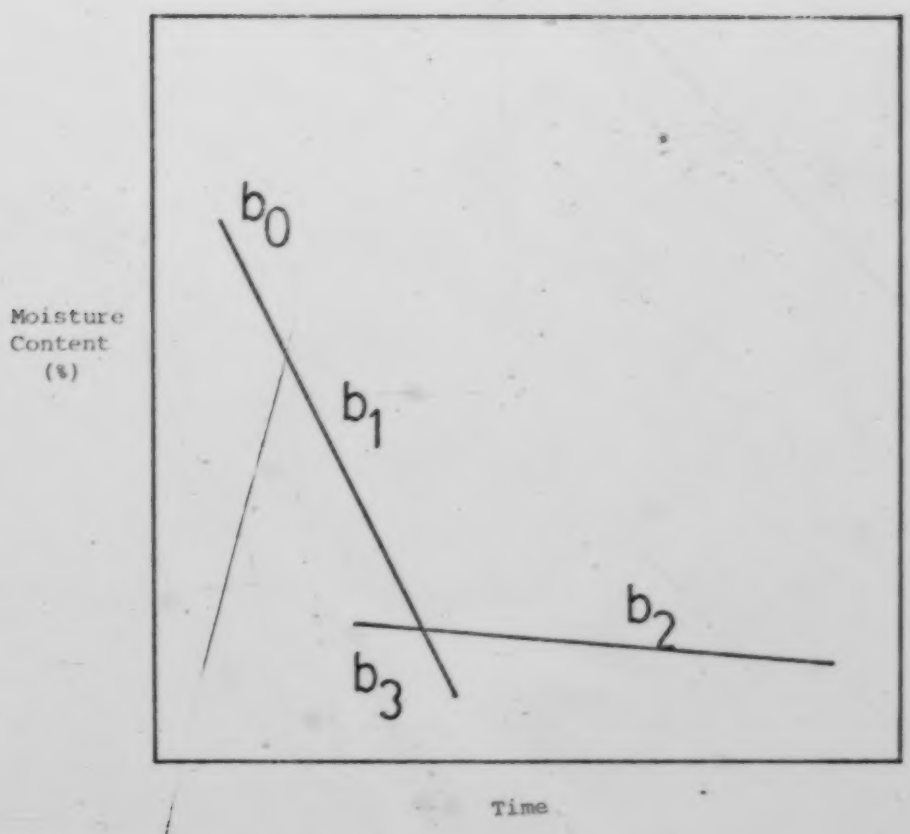

Figure: 3 Schematic Representation of a Drying Curve and Associated Regression Coefficients

expected to be in equilibrium with the atmospheric moisture. The relative positions of the two lines is defined by b_3 in this model, and as such, it determines that point in time when the drying rate switches from the fast (b_1) to the slow (b_2) rate.

Ultimately the multiple regression model was chosen to describe the drying process as it provided a good fit of the data and because it was the model most readily translated into biological terms.

The drying curve of each cultivar was examined using the multiple regression approach. The drying processes for the genotypes within the two tests were then compared. Multiple regression analysis was performed on the data from each block for each gentoype. The regression coefficients so obtained were compared using analysis of variance, and Duncan's Multiple Range test. Also the b_1 and b_2 regression coefficients were tested for significance (H_0: $b = 0$) using a t-test (Draper and Smith, 1966).

The basic drying process having been described, the influence of the various weather parameters on the drying curves was then studied. Following the model of Meredith and Jenkins (1975), the drying process was considered a physiological process inherent to the plant. Superimposed on this drying process are random fluctuations caused by changes in various weather parameters. Therefore, during the second aspect of the study of drying curves, the residuals from the drying curves estimated by regression analysis in the first part of the study (unexplained variation) were analyzed for their sensitivity to fluctuations of weather parameters taken singly or as a group. Again least squares regression analysis was used to study these relationships.

The weather parameters used are listed on pages 56 and 57. In

addition, six sets of weather data for each test were generated from the daily weather records. These sets were produced by classifying the weather records into those for the day of sampling; and for one, two, three, four and five days before sampling, for each of the eighteen sampling dates for wheat and seventeen sampling dates for barley. The final number of weather characters was then 90. Simple correlations among these characters and with the residuals were calculated.

Simple linear regression was used to relate weather characters to the residuals of the whole data set and of the cultivars. For this approach, the ten weather parameters showing the highest correlations with the residual moisture contents were chosen. Each of these parameters was sorted in ascending order. The relation between the residuals and the weather parameters was quantified using simple linear regression analysis.

The second approach for assessing the influence of weather on the residual moisture content values was to use multiple regression analysis to relate changes of more than one weather parameter to changes in residual values. Weather characters entered into the regression analysis were those found not to be highly correlated. In most cases, the number of parameters employed was limited to four or five. Step-wise multiple regression was used for this section of the analysis.

RESULTS

I. Harvest Methodology

A. Wheat

1. Analysis of Variance

Reference to tables 6 and 7 shows that highly significant differences among the seven wheat genotypes were detected for all characters studied except yield. This fact reaffirms earlier statements that the five cultivars and two experimental lines of this test represented a broad range of types. Highly significant differences were found among harvest treatment means for all characters, including yield. Similarly genotype x harvest treatment interaction means were significantly different for all characters. For those characters whose values could be corrected to a constant moisture basis, the characters seed weight, test weight and yield, this adjustment had a significant effect upon mean values. In addition the primary interaction effects, genotype x moisture adjustment and harvest treatment x moisture adjustment were highly significant for the characters seed weight and test weight.

Table 7 details the analysis of variance for the character yield. The total sum of squares were subdivided into genotypes, harvest treatments and three measures of yield (drying, cleaning and moisture adjustment). As mentioned above, no significant differences in yields could be attributed to genotypic effects. This result was unexpected. Harvest treatments and each of the three measures of yield exerted significant influences on yield means. Thus, both harvesting methods and

Table: 6 Analysis of Variance Table for Several Characters of the Wheat Harvesting Methodology Test

Source of Variation	Degrees of Freedom	Mean Squares					
		Protein	Germination	Seed Weight	Test Weight	Dockage	Tillering[2]
Main Plot							
Replicate	3	1.1	368.5	20.9	11.7	94.9	882.3
Genotype (G)	6	23.5 **[1]	1745.9 **	878.7 **	776.4 **	656.5 **	3637.0 **
Error a	18	2.0	54.4	10.4	3.0	19.2	89.6
Subplot							
Harvest Treatment (T)	9	2.3 **	13613.3 **	57.4 **	317.7 **	371.1 **	3284.9 **(1)[3]
G x T	54	0.2 **	194.5 **	6.1 **	6.6 **	47.2 **	76.5 (6)
Error b	189	0.1	54.9 **	2.6	2.1	7.2	90.6 (21)
Sampling Error	280		14.4				
Subsubplot							
Moisture Adjustment (A)	1			10.4 **	57.2 **		
G x A	6			0.0 **	0.4 **		
T x A	9			0.4 **	2.3 **		
G x T x A	54			0.0	0.0		
Error c	210			0.0	0.0		
Coefficient of Variation (%)							
Main Plot		10.0	9.3	9.9	2.3	60.6	7.1
Subplot		1.8	9.4	4.9	I.9	37.1	7.1
Subsubplot				0.2	0.2		

1 ** indicates significance at the 1% level of significance

2 Treatments represented two plot types as noted in Materials and Methods

3 Degrees of Freedom for Tillering

Table: 7 Analysis of Variance Table for Yield from the Wheat Harvesting Methodology Test

Source of Variation	Degrees of Freedom	Mean Squares	Coefficient of Variation (%)
Mainplot			
Replicate	3	3021100	
Genotype (G)	6	720000	
Error a	18	782740	66.9
Subplot			
Harvest Treatment (T)	9	2980600 **[1]	
G x T	54	146050 *	
Error b	189	94709	23.3
Subsubplot			
Drying (D)	1	138120000 **	
Cleaning (C)	1	3075100 **	
Moisture Adjustment (A)	1	2204900 **	
D x C	1	260	
D x A	1	1564600 **	
C x A	1	623	
D x C x A	1	260	
G x D	6	3127860 **	
G x C	6	102680 **	
G x A	6	71822 **	
G x D x C	6	67	
G x D x A	6	67583 **	
G x C x A	6	48	
G x D x C x A	6	67	
T x D	9	2277400 **	
T x C	9	78397 **	
T x A	9	377100 **	
T x D x C	9	181	
T x D x A	9	388110 **	
T x C x A	9	157	
T x D x C x A	9	181	
G x T x D	54	29983 **	
G x T x C	54	6040 **	
G x T x A	54	7394 **	
G x T x D x C	54	22	
G x T x D x A	54	7314 **	
G x T x C x A	54	18	
G x T x D x C x A	54	22	
Error c	1469	1271	2.7

1 *, ** indicate significance at the 5% and 1% levels of significance respectively

yield measures affected yield values, and yield assessments. Many interaction effects were found to be highly significant.

Coefficient of variation values in most cases were of acceptably low levels (less than 15%). However, the coefficient of variation values for dockage and yield for both main plots and subplots were exceptionally high despite the uniform appearance of the test. Both of these characters were determined at the completion of several field operations; each operation possibly introducing some error into the yield determinations. Perhaps this is the basis for the extreme variability observed for these two characters.

2. Genotypes

The 1976 season was generally favorable. The growing season was exceptionally long - 151 frost-free days. All genotypes were able to ripen and mature fully, even the very late, nonadapted cultivars Glenlea and Pitic 62.

The incidence of disease and pests was low and did not noticably affect the characters studied. Cultivars Neepawa and Norquay were slightly more disease prone than the remaining genotypes. The diseases powdery mildew and in Norquay, loose smut were the most prevalent diseases during the 1976 growing season.

Lodging among cultivars was not pronounced. The tallest cultivars were more prone to lodge than the short genotypes like Norquay, Pitic 62, 70M009002 and 70M110001.

Shattering notes taken late in the growing season suggest Pitic 62 was the cultivar least likely to shatter and Norquay, 70M110001 and 70M009002 were the most likely to shatter. Shattering assessments were of a highly subjective nature and may be further biased by the

relative maturities of the genotypes concerned.

The protein contents of the cultivars reflected the division between the two types present in the study (table 8). The hard red spring wheats, Park and Neepawa, exhibited substantially higher protein contents than the utility types, Norquay, Glenlea, Pitic 62, 70M009002 and 70M110001. The lowest protein values were recorded for Norquay.

Germination values were generally low, reflecting the effects of the early harvest treatments. Glenlea gave the lowest germination values, and the genotypes 70M009002, Park, 70M110001 and Pitic 62 demonstrated the highest germination capacities (table 8).

Seed weights for the genotypes (table 8) were similar to those reported previously (Attinaw, 1977). Glenlea, characteristically a large seeded cultivar, had the highest seed weight mean. Pitic 62 was found to have the lowest seed weight of the seven genotypes under study. Seed weights adjusted to 10%mcwb gave higher values than their unadjusted counterparts. Interaction of genotypes and moisture adjustment was highly significant from analysis of variance, however assessment of the seven genotypes using Duncan's Multiple Range test was identical for the two seed weight values.

Genotypic test weights averaged over all treatments differed slightly from Attinaw's results (1977). Test weights were generally lower in the current experiment, again reflecting the influence of the early harvest treatments as much as seasonal differences (table 8). During the present experiment, Park displayed the highest test weight and Pitic 62 the lowest. As with seed weight, adjusting test weights to a constant moisture basis inflated values over their unadjusted counterparts. Using adjusted values, the test weights of Neepawa and

Table: 8 Means of Seven Wheat Genotypes (averaged over treatments and replicates) for Several Characters

Genotype	Character										
	Protein (%)	Germination[1] (%)	Seed[2] Weight (g/1000 k)	Seed Weight Unadjusted (g/1000 k)	Seed Weight Adjusted (g/1000 k)	Test[2] Weight (kg/hl)	Test Weight Unadjusted (kg/hl)	Test Weight Adjusted (kg/hl)	Dockage (%)	Tillering (t/m)	Yield[3] (g/2.3 m^2)
Park	14.9 a[4]	82.6 ab	32.0 cd	31.8 cd	32.1 cd	78.5 a	78.1 a	78.8 a	4.9 c	155 b	1242 a
Neepawa	15.2 a	74.9 d	32.7 c	32.6 c	32.9 c	77.3 b	76.9 bc	77.6 b	8.5 b	170 a	1306 a
Norquay	13.2 d	77.9 c	31.4 d	31.2 d	31.6 d	73.8 e	73.4 e	74.2 e	4.7 c	118 de	1319 a
Glenlea	13.4 cd	71.2 e	38.6 a	38.5 a	38.7 a	76.6 c	76.3 c	76.8 c	9.1 b	110 e	1378 a
Pitic 62	13.5 bcd	80.7 b	27.7 e	27.5 e	27.9 e	69.2 f	68.8 f	69.7 f	15.1 a	132 cd	1341 a
70M009002	14.2 b	84.0 a	31.4 d	31.2 d	31.5 d	75.7 d	75.4 d	76.1 d	3.8 c	121 cde	1372 a
70M110001	14.0 bc	82.3 ab	34.2 b	34.1 b	34.3 b	77.4 b	77.1 b	77.6 b	4.4 c	133 c	1293 a
Mean	14.1	79.1	32.6	32.4	32.7	75.5	75.2	75.8	7.2	134	1322

1 Means averaged over samples as well as treatments and replicates

2 Means averaged over moisture adjustment as well as treatments and replicates

3 Means averaged over drying, moisture adjustment and cleaning as well as treatments and replicates

4 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

Glenlea became indistinguishable; whereas, using unadjusted test weights Neepawa had a significantly higher test weight mean than Glenlea.

Dockage values for the latest cultivar Pitic 62 were significantly higher than those of the remaining cultivars. Glenlea and Neepawa gave intermediate and similar dockage means. The remaining four genotypes produced relatively little dockage (table 8).

Analysis of variance indicated that significant differences existed among the seven genotypes for the character tillering. Neepawa and Park, the two hard red spring wheats, demonstrated the most tillering (table 8). The remaining five genotypes fell into three overlapping groups with respect to tillering capacity. Although significant differences were detected between the two treatments (rows adjacent to blank guard rows producing more tillers/m than rows within solid stands), no significant genotype x treatment interaction effects were found. This would suggest that all genotypes responded in a similar manner to the presence of an adjacent blank row with increased tillering.

Yield was the only character for which significant differences among the seven genotypes could not be detected (table 8). This result was unexpected as the seven genotypes used in this study commonly display a wide range of yielding abilities (Alberta Cereal and Oilseed Advisory Committee, 1977; Attinaw, 1977). The utility wheats, Pitic 62, Glenlea and Norquay, generally out-yield the hard red spring wheats, Park and Neepawa (Alberta Cereal and Oilseed Advisory Committee, 1977). Attinaw (1977) reported that at the Ellerslie station, experimental line 70M110001 yielded as well as Neepawa, Norquay and Glenlea, and that 70M009002 yielded as well as Park.

Significant genotype x yield measure interactions were detected

in four cases. Table 9 lists the genotypic means of wet and dry weight yields. Significant differences among the seven wheat genotypes for either measure of yield were not detected by analysis of variance. The genotype x cleaning, and genotype x moisture adjustment interaction terms were also highly significant. For both (tables 10 and 11) no significant genotypic differences were found, and assessments of the seven genotypes were uninfluenced. The fourth interaction found to be significant was the second order interaction, genotype x drying x moisture adjustment. Significant differences among the seven genotypes were detected using the yield measure wet, unadjusted weight (table 12). Using this measure the genotypes were separated into two broad overlapping groups by Duncan's Multiple Range test. Glenlea and Pitic 62 gave the highest, and Park the lowest wet, unadjusted weight values. For the remaining three yield measures, genotypic means were not significantly different by analysis of variance.

3. Harvest Treatments

Protein contents were highest for the conventional swathing treatment, harvest treatment 1, and the straight combining treatment, harvest treatment 9 (table 13). Swath and thresh treatments 4 and 6, as well as straight combining treatments 8 and 10 also gave high protein values. The lowest values were obtained from the earliest treatments, treatments 2 and 3. It is interesting to note that treatments 8 and 9, straight combining treatments made on the same day produced significantly different mean protein values. The second last harvest treatment, straight combining in plots with no

Table: 9 Wheat Genotype x Drying Interaction Means (averaged over harvest treatments, cleaning, moisture adjustment and replicates) for Yield (g/2.3 m^2)

Genotype	Drying	
	Wet Weight	Dry Weight
Park	1445 a[1]	1038 a
Neepawa	1562 a	1051 a
Norquay	1554 a	1084 a
Glenlea	1664 a	1092 a
Pitic 62	1631 a	1051 a
70M009002	1614 a	1131 a
70M110001	1520 a	1066 a
Mean	1570	1073

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

Table: 10 Wheat Genotype x Cleaning Interaction Means (averaged over harvest treatments, drying, moisture adjustment and replicates) for Yield (g/2.3 m^2)

Genotype	Cleaning	
	Uncleaned Weight	Cleaned Weight
Park	1268 a[1]	1216 a
Neepawa	1351 a	1262 a
Norquay	1344 a	1293 a
Glenlea	1426 a	1330 a
Pitic 62	1411 a	1271 a
70M009002	1394 a	1351 a
70M110001	1317 a	1270 a
Mean	1359	1285

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

Table: 11 Wheat Genotype x Moisture Adjustment Interaction Means (averaged over harvest treatments, drying, cleaning and replicates) for Yield (g/2.3 m^2)

Genotype	Moisture Adjustment	
	Unadjusted Weight	Adjusted Weight
Park	1192 a[1]	1292 a
Neepawa	1272 a	1341 a
Norquay	1280 a	1358 a
Glenlea	1367 a	1389 a
Pitic 62	1330 a	1352 a
70M009002	1332 a	1412 a
70M110001	1259 a	1328 a
Mean	1290	1353

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

Table: 12 Wheat Genotype x Drying x Moisture Adjustment Interaction Means (averaged over harvest treatments, cleaning and replicates) for Yield (g/2.3 m^2)

Genotype	Drying			
	Wet Weight		Dry Weight	
	Moisture Adjustment			
	Unadjusted Weight	Adjusted Weight	Unadjusted Weight	Adjusted Weight
Park	1350 b[1]	1540 a	1033 a	1044 a
Neepawa	1497 ab	1627 a	1047 a	1055 a
Norquay	1482 ab	1626 a	1078 a	1090 a
Glenlea	1644 a	1683 a	1090 a	1094 a
Pitic 62	1616 a	1646 a	1045 a	1057 a
70M009002	1540 ab	1689 a	1125 a	1136 a
70M110001	1456 ab	1584 a	1062 a	1071 a
Mean	1512	1628	1068	1078

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

Table: 13 Means of Ten Wheat Harvesting Treatments (averaged over genotypes and replicates) for Several Characters

Harvest Treatment	Character									
	Protein (%)	Germination[1] (%)	Seed Weight[2] (g/1000 k)	Seed Weight Unadjusted (g/1000 k)	Seed Weight Adjusted (g/1000 k)	Test Weight[2] (kg/hl)	Test Weight Unadjusted (kg/hl)	Test Weight Adjusted (kg/hl)	Dockage (%)	Yield[3] (g/2.3 m^2)
1	14.4 a[4]	90.6 b	31.2 cd	31.1 cd	31.3 cd	76.6 bc	76.4 bc	76.8 bcd	11.4 a	1295 d
2	13.7 e	52.4 f	30.6 d	30.5 d	30.6 d	69.9 e	69.8 e	70.0 g	7.8 ab	1460 a
3	13.7 e	77.5 d	31.9 bc	31.7 bc	32.1 bc	76.2 c	75.7 c	76.8 cd	9.6 ab	1346 bcd
4	14.0 bcd	62.9 e	33.0 a	32.8 a	33.2 a	74.5 d	74.0 d	75.0 f	8.2 ab	1406 ab
5	13.8 de	79.7 cd	32.9 a	32.6 ab	33.2 a	76.5 c	75.8 c	77.3 bc	9.4 ab	1396 abc
6	14.4 bc	84.5 c	33.5 a	33.5 a	33.6 a	76.0 c	75.9 c	76.2 de	11.6 a	1369 bcd
7	13.9 cde	60.5 e	33.2 a	33.1 a	33.3 a	74.1 d	73.9 d	74.4 f	7.1 b	1368 bcd
8	14.2 b	93.0 ab	32.8 ab	32.7 ab	32.8 ab	77.6 ab	77.4 ab	77.8 ab	2.3 c	1192 e
9	14.6 a	92.2 ab	33.1 a	33.0 a	33.1 ab	78.5 a	78.3 a	78.7 a	2.7 c	1317 cd
10	14.1 bc	97.4 a	33.6 a	33.5 a	33.8 a	74.9 d	74.6 d	75.2 ef	2.1 c	1066 f
Mean	14.1	79.1	32.6	32.4	32.7	75.5	75.2	75.8	7.2	1322

1 Means averaged over samples as well as genotypes and replicates

2 Means averaged over moisture adjustment as well as genotypes and replicates

3 Means averaged over drying, moisture adjustment and cleaning as well as genotypes and replicates

4 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

bordering guard rows exhibited a higher protein mean than treatment 8.

Percent germination was another character significantly influenced by the harvesting treatments utilized for this study. High germination means for the straight combining and conventional system contrast the extremely poor germination of seed harvested by treatment 2, swath and thresh one week prior to the physiological maturity of the earliest cultivar. The poorest germination means were found to be associated with harvest at high moisture content, either because of early harvesting or from precipitation prior to harvest (treatments 2, 3, 5 and 7). Significant amounts of fungal contamination were found in the course of the germination tests for each of these harvest treatments. Commonly occuring contaminates were bacteria, and the fungal genera Cochliobolus sp., Alternaria sp. and Fusarium sp. (Skoropad and Tewari, 1976). Such contamination by storage fungi and bacteria is known to cause deterioration in grain quality and germination (Wallace and Sinha, 1969; Jorgensen, 1974) and may have obscured differences in germination capacity more directly attributable to the harvesting treatments.

The character seed weight responded to the influence of the various harvesting treatments (table 13). The lowest seed weights were produced by treatment 1 and treatment 2. Treatment 3 gave an intermediate seed weight value. The seed weights from harvest treatments 4 through 10 were high and indistinguishable. In addition the interaction of harvest treatment x moisture adjustment had a highly significant influence on seed weight means (table 13). As with genotypes, harvest treatment seed weights adjusted to 10%mcwb were higher than their unadjusted counterparts. Based upon Duncan's Multiple Range values, only for treatments 5, swath and thresh at the physiological maturity of Norquay and 70M009002, and

9, straight combining in plots with blank guard rows, did moisture adjustment produce a detectable change in rank relative to the other treatments.

Test weight means were significantly influenced by the type of harvesting operation employed (table 13). The highest test weights were produced by the straight combining treatments 8 and 9; the lowest test weight means came from treatments 2, 4, 7 and 10. Significant treatment x moisture adjustment effects were found for test weight as well as for seed weight. Using adjusted test weights, the harvest treatments were separated into seven groups; whereas, using unadjusted test weights only five groups were detected by Duncan's Multiple Range test. Also the harvest treatments producing intermediate test weight means, treatments 1, 6, 5 and 3 showed some switching of relative position from one measure to the other.

The harvesting operations had a significant effect upon dockage values (table 13) - some treatments producing more dockage than others. Treatments 6, 1, 3, 5, 4 and 2 had the highest dockage means; whereas, straight combining methods 8, 9 and 10 gave the lowest dockage values.

Harvesting treatments had a significant effect on the character yield. Harvest treatments 2, 4 and 5 gave the highest yield values, and the last harvest treatment, treatment 10, produced the lowest yield values. The conventional system, harvest treatment 1, gave one of the lowest yield means. Harvest treatment 9 displayed a significantly higher yield than treatment 8 (table 13).

Four of the seven possible harvest treatment x yield measure interaction terms were found to be highly significant by analysis

of variance (table 7). The significant interaction terms included harvest treatment x drying, treatment x cleaning, treatment x moisture adjustment and harvest treatment x drying x moisture adjustment. Table 14 contains the harvest treatment x drying interaction means. Groupings of the harvest treatments based upon Duncan's Multiple Range values are considerably different for the two measures wet and dry weights (table 14). For example, harvest treatment 2 gave the highest wet weight yield and one of the lowest dry weight yields. The converse was true of treatment 9.

Harvest treatment x cleaning interaction means are listed in table 15. The grouping of the treatments based upon Duncan's Multiple Range values are different for the uncleaned and cleaned weights. The differences in groupings between these two measures were not as dramatic as those observed for the wet and dry weights.

The harvest treatment x moisture adjustment interaction term was also found significant. Again, the groupings of the ten treatments were dissimilar for the two yield measures unadjusted and adjusted weights (table 16). Treatments 6 and 9 appeared to be the most sensitive to moisture adjustment. Both of these treatments exhibited high adjusted weights and low unadjusted weights in relation to the other harvest treatments.

Table 17 contains the harvest treatment x drying x moisture adjustment interaction means. Each of the four yield measures produced a different grouping of the harvest treatments, based upon Duncan's Multiple Range test. However the wet and the dry yield measures appeared more alike than the two unadjusted and the two adjusted measures in the assessments of the ten treatments that they produced.

Table: 14 Wheat Harvest Treatment x Drying Interaction Means (averaged over genotypes, cleaning, moisture adjustment and replicates) for Yield (g/2.3 m^2)

Harvest Treatment	Drying	
	Wet Weight	Dry Weight
1	1496 a[1]	1094 bc
2	1928 a	992 d
3	1644 bc	1049 c
4	1704 b	1108 ab
5	1697 b	1095 bc
6	1612 c	1126 ab
7	1609 c	1128 ab
8	1337 e	1048 c
9	1482 d	1152 a
10	1190 f	941 e
Mean	1570	1073

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

Table: 15 Wheat Harvest Treatment x Cleaning Interaction Means (averaged over genotypes, drying, moisture adjustment and replicates) for Yield (g/2.3 m^2)

Harvest Treatment	Cleaning	
	Uncleaned Weight	Cleaned Weight
1	1354 cd[1]	1237 d
2	1493 a	1427 a
3	1392 bcd	1301 c
4	1448 ab	1364 b
5	1443 ab	1348 bc
6	1433 ab	1305 bc
7	1408 bc	1328 bc
8	1205 e	1179 e
9	1334 d	1300 c
10	1076 f	1055 f
Mean	1359	1285

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

Table: 16 Wheat Harvest Treatment x Moisture Adjustment Interaction Means (averaged over genotypes, drying, cleaning and replicates) for Yield (g/2.3 m^2)

Harvest Treatment	Moisture Adjustment	
	Unadjusted Weight	Adjusted Weight
1	1273 ef[1]	1318 cd
2	1514 a	1406 ab
3	1338 cd	1355 bc
4	1409 b	1403 ab
5	1373 bc	1420 ab
6	1308 de	1430 a
7	1328 cde	1409 ab
8	1126 g	1259 d
9	1244 f	1391 ab
10	991 h	1141 e
Mean	1290	1353

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

Table: 17 Wheat Harvest Treatment x Drying x Moisture Adjustment Interaction Means (averaged over genotypes, cleaning and replicates) for Yield (g/2.3 m^2)

Harvest Treatment	Drying			
	Wet Weight		Dry Weight	
	Moisture Adjustment			
	Unadjusted Weight	Adjusted Weight	Unadjusted Weight	Adjusted Weight
1	1454 e[1]	1538 d	1092 bc	1097 bc
2	2037 a	1819 a	992 e	992 d
3	1637 c	1651 bc	1039 d	1058 c
4	1719 b	1690 bc	1100 ab	1116 ab
5	1663 bc	1731 b	1082 bcd	1108 ab
6	1491 de	1733 b	1124 ab	1127 ab
7	1531 d	1686 bc	1124 ab	1132 ab
8	1206 g	1467 d	1045 cd	1052 c
9	1338 f	1626 c	1150 a	1155 a
10	1044 h	1337 e	937 f	945 d
Mean	1512	1628	1068	1078

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

4. Genotype x Harvest Treatment Interactions

Significant genotype x harvest treatment interaction effects were found for the six characters studied in this test. For the character, protein content all of the nine alternate harvesting treatments gave high, positive, highly significant correlations with the control method, harvest treatment 1 (table 18). However, none of the alternate treatments reproduced exactly the grouping of the seven genotypes that treatment 1 gave. The highest correlations with the control method were for the straight combining treatments 8 and 9. Treatment 2 exhibited the lowest correlation.

The character germinative ability was also sensitive to genotype x harvest treatment effects. None of the alternate harvest treatments studied in this experiment, produced groupings of the seven genotypes similar to the conventional system (table 19). Significant correlations with the control treatment were found for harvest treatments 7 and 10 only.

The third character to be influenced by genotype x harvest treatment interaction effects was seed weight. The grouping of the genotypes by Duncan's Multiple Range test for the control harvest treatment was unique among the ten treatments (table 20). The correlation values were generally high, positive and highly significant for each of the nine alternate harvest treatments. Treatment 5 gave the highest, and treatment 3 the lowest correlation values. Treatments 7, 8, 9 and 10 produced very similar separations of the genotypes for the character seed weight.

Test weight was another character sensitive to genotype x harvest treatment interaction effects. All harvest treatments, except

Table: 18 Wheat Genotype x Harvest Treatment Interaction Means (averaged over all replicates) and Harvest Treatment Correlation Values (n=28) for Protein (%)

Genotype	Harvest Treatment									
	1	2	3	4	5	6	7	8	9	10
Park	15.0 b[1]	14.5 a	14.8 a	14.8 ab	15.0 a	14.9 ab	14.6 ab	15.0 a	15.6 a	14.7 ab
Neepawa	15.8 a	14.5 a	15.0 a	15.3 a	15.1 a	15.3 a	14.9 a	15.4 a	16.0 a	15.0 a
Norquay	13.4 e	12.9 b	13.0 bc	13.2 d	13.0 c	13.2 d	12.9 d	13.4 d	13.5 c	13.3 d
Glenlea	13.8 de	13.1 b	12.9 c	13.3 d	12.9 c	13.2 d	13.7 c	13.6 cd	14.0 bc	13.7 cd
Pitic 62	14.0 cde	13.2 b	12.9 c	13.4 cd	12.9 c	14.0 cd	13.6 cd	13.6 cd	14.0 bc	13.8 cd
70M009002	14.4 bcd	13.8 ab	13.8 b	14.2 bc	14.0 b	14.2 bc	14.1 bc	13.4 b	14.6 b	14.3 abc
70M110001	14.5 bc	13.9 ab	13.6 bc	13.8 cd	13.9 b	13.9 cd	13.7 c	14.0 bc	14.4 b	14.1 bcd
Mean	14.4	13.7	13.7	14.0	13.8	14.1	13.9	14.2	14.6	14.1
$r_{1.x}$	1.000	0.851**[2]	0.854**	0.898**	0.861**	0.876**	0.893**	0.938**	0.932**	0.901**

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

2 ** indicates significance at the 1% level of significance

Table: 19 Wheat Genotype x Harvest Treatment Interaction Means (averaged over replicates and samples) and Harvest Treatment Correlation Values (n=56) for Germination (%)

Genotype	Harvest Treatment									
	1	2	3	4	5	6	7	8	9	10
Park	89.4 bcd[1]	50.3 ab	85.9 a	71.1 a	89.3 a	91.8 a	58.1 bc	96.7 a	95.4 a	98.5 a
Neepawa	93.2 ab	43.2 bc	67.8 c	54.2 d	73.2 b	81.8 bc	55.0 c	92.3 a	91.2 b	97.2 ab
Norquay	85.3 d	51.0 ab	77.7 b	61.6 bcd	83.4 a	87.1 ab	54.0 c	92.5 a	92.1 ab	94.2 c
Glenlea	87.3 cd	33.0 c	66.5 c	56.6 cd	64.4 c	74.3 d	55.9 c	90.3 a	87.0 c	96.4 b
Pitic 62	97.5 a	63.7 a	80.4 ab	63.5 abc	73.7 b	76.7 cd	68.2 a	93.5 a	91.1 b	98.2 a
70M009002	90.1 bcd	65.1 a	82.2 ab	70.0 ab	87.8 a	90.8 a	65.7 ab	94.6 a	94.3 ab	98.8 a
70M110001	91.4 bc	60.5 a	81.9 ab	63.2 abc	86.3 a	89.2 a	66.4 ab	91.4 a	94.2 ab	98.9 a
Mean	90.6	52.4	77.5	62.9	79.7	84.5	60.5	93.0	92.2	97.4
$r_{1.x}$	1.000	0.171	0.105	-0.142	-0.064	-0.186	0.365**[2]	0.155	0.041	0.467**

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

2 ** indicates significance at the 1% level of significance

Table: 20 Wheat Genotype x Harvest Treatment Interaction Means (averaged over moisture adjustment and replicates) and Harvest Treatment Correlation Values (n=56) for Seed Weight (g/1000 k)

Genotype	Harvest Treatment									
	1	2	3	4	5	6	7	8	9	10
Park	30.5 bc[1]	31.1 b	32.1 bc	32.5 bcd	31.8 d	33.3 c	31.9 cd	32.0 cd	32.0 cd	32.5 cd
Neepawa	31.6 bc	30.8 b	30.1 cd	33.7 bc	33.5 bc	33.3 c	33.3 bc	33.0 c	33.0 bc	35.0 bc
Norquay	30.5 bc	30.3 b	31.4 bc	32.0 cd	32.3 cd	32.2 c	31.0 d	31.1 d	31.1 d	31.9 d
Glenlea	35.8 a	33.6 a	37.4 a	39.3 a	39.5 a	40.6 a	40.5 a	39.0 a	40.1 a	40.2 a
Pitic 62	27.8 d	24.9 c	27.6 d	28.2 e	27.1 e	27.4 d	28.6 e	27.9 e	29.1 e	28.3 e
70M009002	30.1 c	30.0 b	31.2 bc	30.8 d	31.4 d	32.2 c	32.5 cd	31.4 cd	32.0 cd	32.3 d
70M110001	32.0 b	33.4 a	33.5 b	34.3 b	34.8 b	35.7 b	34.5 b	34.8 b	34.0 b	35.1 b
Mean	31.2	30.6	31.9	33.0	32.9	33.5	33.2	32.8	33.1	33.6
$r_{1.x}$	1.000	0.802**[2]	0.726**	0.934**	0.964**	0.919**	0.931**	0.916**	0.940**	0.919**

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

2 ** indicates significance at the 1% level of significance

the earliest two, gave groupings of the seven genotypes similar but not identical to the grouping achieved by the control (table 21). Correlation values between each of the alternate harvest treatments and the control method were high, positive and highly significant for all treatments - harvest treatments 8, 7 and 9 displaying the highest correlation values.

Genotype x harvest treatment interactions had a significant effect upon dockage values. Seven of the nine alternate harvesting regimes gave positive, highly significant correlations with treatment 1 (table 22). Treatments 2 and 7 did not. The correlation values were not high. The highest correlation, that between treatments 1 and 9, was 0.611 (variation explained: 37%). Not one of the alternate harvesting treatments was found to reproduce the groupings of the seven genotypes obtained for the conventional harvesting system.

Significant genotype x harvest treatment interaction effects were found for yield. For nine of the ten harvest treatments, including the control method, no significant differences could be detected among the seven genotypes under study (table 23). For harvest treatment 9, Pitic 62 was found to yield significantly more than all the remaining genotypes except Glenlea.

Second and third order interactions involving genotypes, harvest treatments and yield measures were highly significant in four instances for the character yield. Considering the genotype x harvest treatment x drying interaction, for only three of the twenty possible treatment combinations was it possible to distinguish among the genotypes for yield. These treatments were harvest treatment 9 with wet weights, and harvest treatments 3 and 9 with dry weights (table 24).

For the interaction genotype x harvest treatment x cleaning

Table: 21 Wheat Genotype x Harvest Treatment Interaction Means (averaged over moisture adjustment and replicates) and Harvest Treatment Correlation Values (n=56) for Test Weight (kg/hl)

Genotype	Harvest Treatment									
	1	2	3	4	5	6	7	8	9	10
Park	79.9 a[1]	73.0 ab	79.3 a	77.8 a	79.2 a	79.4 a	76.8 a	80.3 a	81.2 a	77.5 ab
Neepawa	79.5 a	69.9 bc	77.4 bc	75.8 b	78.0 ab	78.2 b	76.2 ab	79.9 a	80.7 a	77.0 b
Norquay	74.2 d	68.8 c	75.5 d	72.4 d	75.3 c	74.9 d	71.8 d	76.1 d	76.6 d	72.7 d
Glenlea	78.3 b	68.6 c	76.7 c	75.6 bc	77.5 b	76.5 c	75.6 b	78.6 bc	79.4 bc	78.7 a
Pitic 62	69.6 e	63.4 d	69.2 e	70.3 e	70.5 d	68.4 e	68.5 e	71.3 e	73.4 e	67.9 e
70M009002	76.7 c	71.4 abc	77.1 c	74.2 c	76.9 b	75.4 c	74.2 c	77.8 c	78.5 c	74.3 c
70M110001	78.1 b	74.1 a	78.2 b	75.7 bc	78.2 ab	78.3 b	75.8 ab	79.2 ab	79.6 b	76.4 b
Mean	76.6	69.9	76.2	74.5	76.5	76.0	74.1	77.6	78.5	74.9
$r_{1.x}$	1.000	0.663**[2]	0.890**	0.905**	0.931**	0.954**	0.968**	0.972**	0.967**	0.915**

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

2 ** indicates significance at the 1% level of significance

Table: 22 Wheat Genotype x Harvest Treatment Interaction Means (averaged over replicates) and Harvest Treatment Correlation Values (n=28) for Dockage (%)

Genotype	Harvest Treatment									
	1	2	3	4	5	6	7	8	9	10
Park	8.2 b[1]	1.6 b	6.2 c	6.9 c	6.8 c	9.2 bc	4.3 b	1.8 b	2.5 cd	2.0 bc
Neepawa	17.4 a	3.3 b	10.6 b	9.9 b	11.5 b	13.0 bc	8.9 ab	4.4 a	3.4 bc	2.6 b
Norquay	9.7 ab	4.4 b	7.3 c	4.9 d	5.5 c	6.3 c	5.4 b	1.1 b	1.3 d	1.4 c
Glenlea	17.6 a	6.6 b	12.8 b	9.5 b	13.7 b	14.9 b	8.3 b	2.4 b	3.8 b	2.1 bc
Pitic 62	13.3 ab	31.4 a	19.8 a	16.3 a	18.3 a	25.5 a	12.9 a	4.4 a	5.2 a	3.8 a
70M009002	6.1 b	3.3 b	4.9 c	4.5 d	4.7 c	5.9 c	4.5 b	0.9 b	1.3 d	1.5 c
70M110001	7.4 b	4.3 b	6.0 c	5.0 d	5.4 c	6.4 c	5.7 b	1.1 b	1.5 d	1.1 c
Mean	11.4	7.8	9.6	8.1	9.4	11.6	7.1	2.3	2.7	2.1
$r_{1.x}$	1.000	0.268	0.530**[2]	0.523**	0.512**	0.499**	0.319	0.538**	0.611**	0.407*

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

2 *, ** indicate significance at the 5% and 1% levels of significance respectively

Table: 23 Wheat Genotype x Harvest Treatment Interaction Means (averaged over drying, cleaning, moisture adjustment and replicates) for Yield (g/2.3 m^2)

Genotype	Harvest Treatment									
	1	2	3	4	5	6	7	8	9	10
Park	1259 a[1]	1422 a	1316 a	1319 a	1338 a	1268 a	1268 a	1049 a	1178 b	1002 a
Neepawa	1232 a	1387 a	1339 a	1475 a	1356 a	1491 a	1425 a	1107 a	1275 b	979 a
Norquay	1337 a	1440 a	1364 a	1370 a	1376 a	1312 a	1366 a	1214 a	1283 b	1126 a
Glenlea	1330 a	1495 a	1403 a	1444 a	1538 a	1420 a	1468 a	1191 a	1356 ab	1133 a
Pitic 62	1292 a	1572 a	1135 a	1437 a	1359 a	1432 a	1354 a	1320 a	1489 a	1017 a
70M009002	1369 a	1496 a	1430 a	1400 a	1447 a	1433 a	1437 a	1233 a	1350 b	1129 a
70M110001	1247 a	1408 a	1438 a	1397 a	1360 a	1226 a	1261 a	1234 a	1289 b	1074 a
Mean	1295	1460	1346	1406	1396	1369	1368	1192	1317	1066

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

Table: 24 Wheat Genotype x Harvest Treatment x Drying Interaction Means (averaged over cleaning, moisture adjustment and replicates) for Yield (g/2.3 m^2)

Genotype	Drying: Wet Weight									
	Harvest Treatment									
	1	2	3	4	5	6	7	8	9	10
Park	1437 a[1]	1815 a	1551 a	1557 a	1582 a	1466 a	1472 a	1153 a	1301 c	1118 a
Neepawa	1449 a	1834 a	1645 a	1781 a	1663 a	1782 a	1680 a	1248 a	1444 bc	1093 a
Norquay	1541 a	1862 a	1654 a	1645 a	1650 a	1535 a	1603 a	1357 a	1437 bc	1255 a
Glenlea	1541 a	2034 a	1763 a	1773 a	1921 a	1703 a	1742 a	1352 a	1543 ab	1264 a
Pitic 62	1489 a	2216 a	1445 a	1801 a	1727 a	1716 a	1591 a	1490 a	1696 a	1138 a
70M009002	1573 a	1938 a	1725 a	1682 a	1728 a	1666 a	1692 a	1370 a	1505 abc	1262 a
70M110001	1445 a	1799 a	1726 a	1691 a	1611 a	1416 a	1480 a	1387 a	1446 bc	1203 a
Mean	1496	1928	1644	1704	1697	1612	1609	1337	1482	1190

Genotype	Drying: Dry Weight									
	Harvest Treatment									
	1	2	3	4	5	6	7	8	9	10
Park	1081 a	1029 a	1081 a	1081 a	1094 a	1070 a	1063 a	946 a	1055 b	885 a
Neepawa	1015 a	941 a	1032 a	1170 a	1050 a	1199 a	1170 a	965 a	1106 b	864 a
Norquay	1133 a	1017 a	1074 a	1095 a	1102 a	1090 a	1130 a	1071 a	1129 b	997 a
Glenlea	1120 a	957 a	1043 a	1115 a	1155 a	1137 a	1193 a	1031 a	1168 ab	1002 a
Pitic 62	1097 a	928 a	825 b	1073 a	991 a	1148 a	1117 a	1151 a	1282 a	897 a
70M009002	1165 a	1054 a	1134 a	1117 a	1167 a	1200 a	1181 a	1095 a	1196 ab	997 a
70M110001	1049 a	1017 a	1151 a	1103 a	1108 a	1035 a	1041 a	1080 a	1132 b	946 a
Mean	1094	992	1049	1108	1095	1126	1128	1048	1152	941

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

significant differences among the seven wheat genotypes were found in only two of the twenty possible treatment combinations. Treatment 9 differed markedly from the others with respect to both cleaned and uncleaned weights (table 25).

Genotype x harvest treatment x moisture adjustment interactions had a significant influence on yield values. However, all treatment combinations but one gave the same assessment of the seven genotypes (table 26). For harvest treatment 9, with unadjusted weights, the genotypes were separated into three overlapping groups.

The third order interaction, genotype x harvest treatment x drying x moisture adjustment was also found to have a significant influence on yield. For six of the forty treatment combinations, significant differences among the genotypes were found by analysis of variance (table 27). The highest correlation with the control (treatment 1, with dry, unadjusted weights) was obtained with treatment 1, with dry, adjusted values. The harvest treatments often producing the highest correlations with the control treatment combination were harvest treatments 2 and 10. The yield measure generally giving the highest correlation values was the dry, unadjusted measure.

Table 28 gives the drying x moisture adjustment means. Dry weights were substantially less than wet weights as would be expected. Moisture adjustment exhibited its major influence upon wet weights. The dry unadjusted and adjusted weights were indistinguishable.

B. Barley

1. Analysis of Variance

The analysis of variance tables, tables 29 and 30, give the

Table: 25 Wheat Genotype x Harvest Treatment x Cleaning Interaction Means (averaged over drying, moisture adjustment and replicates) for Yield (g/2.3 m^2)

Genotype	Cleaning: Uncleaned Weight									
	Harvest Treatment									
	1	2	3	4	5	6	7	8	9	10
Park	1302 a[1]	1431 a	1349 a	1355 a	1376 a	1318 a	1291 a	1058 a	1192 c	1011 a
Neepawa	1313 a	1403 a	1390 a	1531 a	1413 a	1568 a	1476 a	1128 a	1294 bc	991 a
Norquay	1389 a	1461 a	1401 a	1397 a	1406 a	1348 a	1398 a	1220 a	1291 bc	1133 a
Glenlea	1421 a	1525 a	1463 a	1493 a	1611 a	1500 a	1516 a	1204 a	1379 ab	1145 a
Pitic 62	1361 a	1691 a	1207 a	1516 a	1440 a	1566 a	1422 a	1348 a	1524 a	1035 a
70M009002	1404 a	1513 a	1457 a	1424 a	1475 a	1470 a	1464 a	1238 a	1359 abc	1138 a
70M110001	1286 a	1429 a	1472 a	1424 a	1390 a	1259 a	1291 a	1240 a	1298 bc	1080 a
Mean	1354	1493	1392	1448	1444	1433	1408	1205	1334	1076

Genotype	Cleaning: Cleaned Weight									
	Harvest Treatment									
	1	2	3	4	5	6	7	8	9	10
Park	1216 a	1414 a	1283 a	1283 a	1300 a	1218 a	1245 a	1040 a	1164 c	992 a
Neepawa	1151 a	1372 a	1287 a	1420 a	1299 a	1413 a	1374 a	1085 a	1255 bc	967 a
Norquay	1284 a	1418 a	1326 a	1344 a	1346 a	1277 a	1335 a	1208 a	1275 bc	1118 a
Glenlea	1240 a	1466 a	1342 a	1395 a	1465 a	1340 a	1419 a	1179 a	1333 abc	1121 a
Pitic 62	1225 a	1453 a	1062 a	1358 a	1278 a	1298 a	1286 a	1293 a	1455 a	999 a
70M009002	1334 a	1479 a	1402 a	1375 a	1420 a	1396 a	1410 a	1227 a	1342 ab	1121 a
70M110001	1208 a	1387 a	1405 a	1370 a	1330 a	1192 a	1230 a	1227 a	1279 bc	1069 a
Mean	1237	1427	1301	1364	1348	1305	1328	1180	1300	1055

1. Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

Table 26 Wheat Genotype x Harvest Treatment x Moisture Adjustment Interaction Means (averaged over drying, cleaning and replicates) for Yield (g/2.3 m^2)

Genotype	Moisture Adjustment: Unadjusted Weight									
	Harvest Treatment									
	1	2	3	4	5	6	7	8	9	10
Park	1220 a[1]	1436 a	1272 a	1295 a	1261 a	1187 a	1225 a	984 a	1105 c	932 a
Neepawa	1232 a	1441 a	1322 a	1480 a	1329 a	1406 a	1381 a	1032 a	1188 bc	910 a
Norquay	1312 a	1488 a	1349 a	1367 a	1342 a	1232 a	1328 a	1134 a	1199 bc	1049 a
Glenlea	1308 a	1576 a	1436 a	1477 a	1553 a	1397 a	1428 a	1141 a	1298 ab	1056 a
Pitic 62	1258 a	1671 a	1165 a	1465 a	1385 a	1398 a	1316 a	1268 a	1431 a	942 a
70M009002	1344 a	1538 a	1403 a	1393 a	1410 a	1361 a	1390 a	1162 a	1273 abc	1048 a
70M110001	1236 a	1451 a	1419 a	1389 a	1329 a	1172 a	1225 a	1158 a	1212 bc	997 a
Mean	1273	1514	1338	1409	1373	1308	1328	1126	1244	991

Genotype	Moisture Adjustment: Adjusted Weight									
	Harvest Treatment									
	1	2	3	4	5	6	7	8	9	10
Park	1298 a	1409 a	1360 a	1343 a	1415 a	1349 a	1310 a	1114 a	1251 a	1072 a
Neepawa	1231 a	1334 a	1356 a	1471 a	1383 a	1576 a	1469 a	1181 a	1361 a	1048 a
Norquay	1361 a	1391 a	1379 a	1374 a	1410 a	1393 a	1405 a	1294 a	1367 a	1202 a
Glenlea	1353 a	1415 a	1370 a	1411 a	1523 a	1443 a	1508 a	1242 a	1414 a	1210 a
Pitic 62	1327 a	1473 a	1105 a	1409 a	1333 a	1466 a	1391 a	1372 a	1548 a	1092 a
70M009002	1394 a	1454 a	1456 a	1407 a	1484 a	1505 a	1483 a	1304 a	1428 a	1211 a
70M110001	1258 a	1365 a	1458 a	1405 a	1390 a	1279 a	1296 a	1309 a	1365 a	1152 a
Mean	1318	1406	1355	1403	1420	1430	1409	1259	1391	1141

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

Table: 27 Wheat Genotype x Harvest Treatment x Drying x Moisture Adjustment Interaction Means (averaged over cleaning and replicates) and Treatment Correlation Values (n=56) for Yield (g/2.3 m^2)

Genotype	Drying: Wet Weight				Moisture Adjustment: Unadjusted Weight					
	Harvest Treatment									
	1	2	3	4	5	6	7	8	9	10
Park	1363 a[1]	1842 c	1472 a	1520 a	1442 c	1307 a	1391 a	1027 a	1160 c	982 a
Neepawa	1455 a	1941 bc	1621 a	1790 a	1621 bc	1614 a	1594 a	1101 a	1273 bc	958 a
Norquay	1494 a	1958 bc	1635 a	1645 a	1596 bc	1378 a	1530 a	1203 a	1275 bc	1108 a
Glenlea	1498 a	2195 ab	1835 a	1845 a	1963 a	1654 a	1665 a	1249 a	1428 ab	1111 a
Pitic 62	1427 a	2418 a	1516 a	1868 a	1793 ab	1648 a	1520 a	1390 a	1579 a	995 a
70M009002	1523 a	2020 bc	1683 a	1681 a	1669 bc	1525 a	1604 a	1233 a	1354 bc	1103 a
70M110001	1422 a	1884 bc	1697 a	1684 a	1562 bc	1313 a	1415 a	1240 a	1294 bc	1052 a
Mean	1454	2037	1637	1719	1664	1491	1531	1206	1338	1044
$r_{1DU.x}$	0.875**[2]	0.519**	0.439**	0.423**	0.459**	0.398**	0.440**	0.425**	0.213	0.661**

Genotype	Drying: Wet Weight				Moisture Adjustment: Adjusted Weight					
	Harvest Treatment									
	1	2	3	4	5	6	7	8	9	10
Park	1512 a	1788 a	1630 a	1595 a	1724 a	1626 a	1554 a	1279 a	1442 a	1254 a
Neepawa	1443 a	1727 a	1668 a	1772 a	1704 a	1950 a	1765 a	1395 a	1614 a	1228 a
Norquay	1587 a	1765 a	1672 a	1646 a	1703 a	1692 a	1676 a	1511 a	1600 a	1403 a
Glenlea	1584 a	1873 a	1691 a	1701 a	1879 a	1752 a	1819 a	1454 a	1658 a	1418 a
Pitic 62	1551 a	2014 a	1375 a	1733 a	1661 a	1784 a	1661 a	1589 a	1814 a	1280 a
70M009002	1623 a	1855 a	1767 a	1684 a	1786 a	1807 a	1781 a	1507 a	1656 a	1420 a
70M110001	1467 a	1713 a	1755 a	1697 a	1660 a	1520 a	1545 a	1534 a	1598 a	1354 a
Mean	1538	1819	1651	1690	1731	1733	1686	1467	1626	1337
$r_{1DU.x}$	0.990**	0.599**	0.397**	0.428**	0.539**	0.367**	0.447**	0.513**	0.279*	0.654**

Table: 27 continued

Genotype	Drying: Dry Weight				Moisture Adjustment: Unadjusted Weight					
	Harvest Treatment									
	1	2	3	4	5	6	7	8	9	10
Park	1078 a	1029 a	1072 a	1070 a	1081 a	1067 a	1060 a	942 a	1049 b	882 a
Neepawa	1010 a	940 a	1022 a	1169 a	1038 a	1197 a	1168 a	964 a	1103 b	861 a
Norquay	1131 a	1018 a	1062 a	1088 a	1088 a	1086 a	1125 a	1066 a	1122 b	991 a
Glenlea	1117 a	958 a	1036 a	1109 a	1143 a	1141 a	1191 a	1033 a	1167 ab	1002 a
Pitic 62	1090 a	925 a	815 b	1062 a	977 a	1147 a	1112 a	1146 a	1283 a	890 a
70M009002	1166 a	1056 a	1122 a	1105 a	1152 a	1197 a	1177 a	1090 a	1192 ab	992 a
70M110001	1049 a	1017 a	1142 a	1094 a	1096 a	1032 a	1036 a	1076 a	1131 b	942 a
Mean	1092	992	1039	1099	1082	1124	1124	1045	1150	937
$r_{1DU.x}$	1.000	0.655**	0.403**	0.514**	0.590**	0.544**	0.494**	0.518**	0.323*	0.669**

Genotype	Drying: Dry Weight				Moisture Adjustment: Adjusted Weight					
	Harvest Treatment									
	1	2	3	4	5	6	7	8	9	10
Park	1083 a	1030 a	1090 a	1092 a	1106 a	1073 a	1067 a	949 a	1060 a	888 a
Neepawa	1019 a	941 a	1042 a	1170 a	1062 a	1201 a	1173 a	966 a	1108 a	868 a
Norquay	1135 a	1066 a	1085 a	1103 a	1117 a	1093 a	1135 a	1076 a	1135 a	1002 a
Glenlea	1122 a	956 a	1050 a	1121 a	1166 a	1134 a	1196 a	1029 a	1170 a	1002 a
Pitic 62	1104 a	931 a	834 b	1084 a	1005 a	1149 a	1121 a	1156 a	1282 a	904 a
70M009002	1164 a	1053 a	1145 a	1130 a	1181 a	1204 a	1185 a	1100 a	1200 a	1002 a
70M110001	1049 a	1017 a	1161 a	1113 a	1120 a	1038 a	1047 a	1084 a	1132 a	950 a
Mean	1097	992	1058	1116	1108	1127	1132	1052	1155	945
$r_{1DU.x}$	0.999**	0.668**	0.403**	0.530**	0.593**	0.541**	0.497**	0.522**	0.335*	0.668**

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

2 *, ** indicate significance at the 5% and 1% levels of significance respectively

Table: 28 Drying x Moisture Adjustment Interaction Means (averaged over genotypes, harvest treatments, cleaning and replicates) for Yield (g/2.3 m^2) from the Wheat Harvesting Methodology Test

Moisture Adjustment	Drying		Mean
	Wet Weight	Dry Weight	
Unadjusted Weight	1512 b[1]	1068 c	1290
Adjusted Weight	1628 a	1078 c	1353
Mean	1570	1073	1322

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

Table: 29 Analysis of Variance Table for Several Characters from the Barley Harvesting Methodology Test

Source of Variation	Degrees of Freedom	Mean Squares					
		Protein	Germination	Germination Resistance	Uniformity Factor	Seed Weight	Test Weight
Main Plot							
Replicate	3	0.7	11.4	3.1	14.5	0.9	3.4
Genotype (G)	5	8.9 **[1]	22.0 **	208.5 **	6.9	97.3 **	190.8 **
Error a	15	0.3	2.2	8.1	4.1	2.0	1.7
Subplot							
Harvest Treatment (T)	2	0.0	170.4 **	339.5 **	75.4 **	4.1	361.9 **
G x T	10	0.1	35.0 **	17.7 *	21.9 **	1.7	26.3 **
Error b	36	0.1				4.1	2.0
Pooled Error	108		4.1	7.2	3.0		
Subsubplot							
Moisture Adjustment (A)	1					0.6 **	2.0 **
G x A	5					0.0	0.1
T x A	2					0.0 **	0.0 **
G x T x A	10					0.0 **	0.0 **
Error c	54					0.0	0.0
Coefficient of Variation (%)							
Main Plots		3.6	1.5	9.8	16.4	5.0	2.5
Subplots		2.1	2.1	9.2	14.2	7.1	2.8
Subsubplots						0.1	0.1

[1] *, ** indicate significance at the 5% and 1% levels of significance respectively

Table: 30 Analysis of Variance Table for Yield from the Barley Harvesting Methodology Test

Source of Variation	Degrees of Freedom	Mean Squares	Coefficient of Variation (%)
Main Plot			
Replicate	3	157600	
Genotype (G)	5	208950	
Error a	15	78049	27.7
Subplot			
Harvest Treatment (T)	2	1095900 **[1]	
G x T	10	74009	
Error b	36	56156	23.5
Subsubplot			
Drying (D)	1	5557800 **	
Moisture Adjustment (A)	1	190260 **	
D x A	1	225730 **	
G x D	5	26095 **	
G x A	5	24773 **	
G x D x A	5	23819 **	
T x D	2	58466	
T x A	2	11188	
T x D x A	2	8067	
G x T x D	10	21200 **	
G x T x A	10	16075 **	
G x T x D x A	10	15486 **	
Error c	162	1734	4.1

[1] *, ** indicate significance at the 5% and 1% levels of significance respectively.

mean square values and their significance for the F-test comparison of variances for the characters studied in this experiment. Genotypic effects were significant for all characters except two; the germination uniformity factor and yield were the two exceptions. The harvest treatments had a significant influence on four of the seven characters. Protein content, uniformity factor and seed weight were unaffected by harvesting operations. Significant differences among the genotype x harvest treatment interaction means were found for the characters germinative ability, germination resistance, uniformity factor and test weight. For the characters seed weight and test weight a comparison of unadjusted values and values adjusted to 10%mcwb was made. Significant differences between the unadjusted and adjusted means for both characters were found. In addition, the interaction terms involving genotypes were highly significant.

The analysis of variance for yield is presented in table 30. No significant differences among cultivar means were demonstrated. The factors harvest treatments, drying and moisture adjustment each had a significant influence on yield means. Genotype x harvest treatment interaction effects were nonsignificant. Significant interaction effects were found for genotype x drying, genotype x moisture adjustment, genotype x drying x moisture adjustment and for the three third order interactions.

Coefficient of variation values for each analysis are given in tables 29 and 30. In most cases, the coefficient of variation values were acceptably low (less than 15%). High coefficient of variation values for the characters uniformity factor and yield were recorded.

The high coefficient of variation values for main plots and subplots of the character uniformity factor may reflect either the nature of the sampling technique or the sensitivity of this measure. Both main plots and subplots for yield gave high coefficient of variation values. As suggested above for wheat yield coefficient values, the complexity of the field operations may be the cause of the observed high variability.

2. Genotypes

The growing season was exceptionally long. All cultivars were able to mature fully. Lodging was severe for all cultivars in this test. The genotypes Conquest, Bonanza and Jubilee appeared more prone to lodging than Olli, Gateway 63 and Galt; which is in contrast to the assessments of previous researchers (Alberta Cereal and Oilseed Advisory Committee, 1977). Disease and pest infestations were mild during the growing season. Scald and net blotch were the most commonly noted diseases. The diseases generally appeared late in the growing season and were not considered serious.

Significant differences among the cultivar means for protein content were found. Olli exhibited the highest overall percent protein mean of the six genotypes (table 31). This is consistent with the fact that Olli is known to be a high protein cultivar (Briggs, 1976). The remaining five genotypes were grouped into three overlapping groups with respect to protein content. Gateway 63 and Conquest had the second highest and Bonanza the lowest protein values. The two feed grade barleys, Galt and Jubilee, had intermediate to low protein contents. The protein contents of the six cultivars were generally high. Those of the malting grade genotypes were somewhat higher than is commonly regarded as acceptable by maltsters (Brewing and Malting Barley Research

Table: 31 Means of Six Barley Genotypes (averaged over all treatments and replicates) for Several Characters

Genotype	Character										
	Protein (%)	Germination[1] (%)	Germination[1] Resistance	Uniformity[1] Factor	Seed Weight[2] (g/1000 k)	Seed Weight Unadjusted (g/1000 k)	Seed Weight Adjusted (g/1000 k)	Test Weight[2] (kg/hl)	Test Weight Unadjusted (kg/hl)	Test Weight Adjusted (kg/hl)	Yield[3] (g/2.3 m^2)
Olli	16.6 a[4]	97.6 a	26.6 b	11.7 a	26.9 c	27.0 c	26.8 c	51.0 c	51.1 c	50.8 c	994 a
Gateway 63	15.2 b	95.4 b	28.3 b	11.9 a	29.0 b	29.1 b	28.9 b	56.9 a	57.1 a	56.6 a	1052 a
Conquest	15.2 b	96.2 b	27.4 b	12.6 a	31.9 a	32.0 a	31.8 a	54.0 b	54.1 b	53.9 b	1078 a
Bonanza	14.4 d	97.8 a	26.9 b	11.7 a	29.3 b	29.3 b	29.3 b	51.0 c	51.0 c	50.9 c	933 a
Galt	14.4 cd	97.4 a	32.8 a	12.7 a	29.4 b	29.4 b	29.3 b	50.5 c	50.6 c	50.4 c	1062 a
Jubilee	14.9 bc	97.3 a	33.0 a	12.8 a	26.2 c	26.3 c	26.2 c	49.2 d	49.3 d	49.1 d	930 a
Mean	15.1	96.9	29.2	12.2	28.8	28.9	28.7	52.1	52.2	52.0	1008

1 Means averaged over samples as well as treatments and replicates

2 Means averaged over moisture adjustment as well as treatments and replicates

3 Means averaged over drying and moisture adjustment as well as treatments and replicates

4 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

Institute, 1976).

Percent germination values were high for all cultivars (table 31). The values for Olli, Bonanza, Galt and Jubilee were similar and significantly higher than the percent germination values of Gateway 63 and Conquest.

The six genotypes split into two groups based upon germination resistance values (table 31). The two late feed cultivars, Galt and Jubilee, showed significantly greater germination resistance than the remaining four malting types of barley.

No significant differences among the cultivars for uniformity factor were detected.

Seed weight means for the six genotypes were separated into three distinct groups by Duncan's Multiple Range test (table 31). Conquest had the highest seed weight, and Olli and Jubilee the lowest seed weight means. Seed weights unadjusted for moisture content were significantly higher than adjusted seed weights. A significant genotype x moisture adjustment term was recorded. This interaction effect, however, did not appreciably influence relative evaluations of the seven genotypes based upon Duncan's Multiple Range test (table 31).

Similarly, significant differences among the genotypic means for test weight, and between unadjusted and adjusted for moisture content values were detected by analysis of variance. Reference to the genotypic means for test weight indicates that Gateway 63 had the highest and Jubilee the lowest test weight means (table 31). Unadjusted test weights were consistently higher than their adjusted counterparts. The interaction of gentoypes x moisture adjustment had a significant influence on test weight values also. However, the relative ordering of genotypic

means was unchanged using adjusted values in place of unadjusted test weights (table 31).

The final character to be considered was yield. Unexpectedly, no significant differences were detected among the six genotypes for this character (Alberta Cereal and Oilseed Advisory Committee, 1977). However all genotype x yield measure interactions were significant. The six genotypes could be separated into two or three overlapping groups using wet weights, unadjusted weights or wet, unadjusted weights (tables 32, 33 and 34). Gateway 63 and Conquest displayed the highest yield values for these yield measures.

3. Harvest Treatments

The use of alternate harvest regimes had little or no effect on three characters measured in this study. No significant differences could be detected among the harvest treatment means for protein content, uniformity factor and seed weight.

Two measures of germination capacity were influenced by harvesting procedures. The second harvest treatment adversely affected the character germinative ability (table 35). Treatments 1 and 3 gave high, very similar germination values. The parameter germination resistance showed the same pattern of results. Treatment 2 produced significantly different values than the control and the late swath and thresh treatments.

The character test weight showed a significant response to the effects of the three harvesting procedures. The conventional system gave the highest test weight values. The test weights of the two

Table: 32 Barley Genotype x Drying Interaction Means (averaged over harvest treatments, moisture adjustment and replicates) for Yield (g/2.3 m^2)

Genotype	Drying	
	Wet Weight	Dry Weight
Olli	1142 abc[1]	845 a
Gateway 63	1218 a	886 a
Conquest	1234 a	922 a
Bonanza	1036 c	830 a
Galt	1200 ab	925 a
Jubilee	1052 bc	807 a
Mean	1147	869

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

Table: 33 Barley Genotype x Moisture Adjustment Interaction Means (averaged over harvest treatment, drying and replicates) for Yield (g/2.3 m^2)

Genotype	Moisture Adjustment	
	Unadjusted Weight	Adjusted Weight
Olli	985 ab[1]	1003 a
Gateway 63	1063 a	1041 a
Conquest	1049 a	1107 a
Bonanza	891 b	975 a
Galt	1013 ab	1111 a
Jubilee	893 b	966 a
Mean	982	1034

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

Table: 34 Barley Genotype x Drying x Moisture Adjustment Interaction Means (averaged over harvest treatments and replicates) for Yield (g/2.3 m^2)

Genotype	Drying			
	Wet Weight		Dry Weight	
	Moisture Adjustment			
	Unadjusted Weight	Adjusted Weight	Unadjusted Weight	Adjusted Weight
Olli	1124 a[1]	1161 a	846 a	845 a
Gateway 63	1236 a	1200 a	890 a	881 a
Conquest	1175 a	1294 a	923 a	920 a
Bonanza	951 c	1120 a	831 a	829 a
Galt	1098 ab	1301 a	928 a	921 a
Jubilee	977 bc	1127 a	810 a	805 a
Mean	1093	1201	871	867

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

Table: 35 Means of Three Barley Harvest Treatments (averaged over all genotypes and replicates) for Several Characters

Harvest Treatment	Character						
	Protein (%)	Germination[1] (%)	Germination[1] Resistance	Uniformity[1] Factor	Seed Weight[2] (g/1000 k)	Test Weight[2] (kg/hl)	Yield[3] ($g/2.3\ m^2$)
1	15.1 a[4]	98.0 a	27.0 c	10.9 a	28.5 a	55.1 a	1061 a
2	15.1 a	94.8 b	32.1 a	13.3 a	29.0 a	49.8 b	1078 a
3	15.1 a	98.0 a	28.3 b	12.6 a	28.9 a	51.4 b	885 b
Mean	15.1	96.9	29.2	12.2	28.8	52.1	1008

1 Means averaged over samples as well as genotypes and replicates

2 Means averaged over moisture adjustment as well as genotypes and replicates

3 Means averaged over drying and moisture adjustment as well as genotypes and replicates

4 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

swath and thresh treatments were indistinguishable (table 35).

Unlike genotypes, harvest treatments had a significant impact upon yield means. Treatment 3, swath and thresh at harvest ripeness, produced a significantly lower yield mean than the remaining two harvest treatments, which were themselves indistinguishable by Duncan's Multiple Range test (table 35).

4. Genotype x Harvest Treatment Interactions

Genotype x harvest treatment interactions appeared less important in the barley test than the wheat test. As stated previously, only four of a possible seven characters displayed significant genotype x harvest treatment interaction terms by analysis of variance. Percent germination, germination resistance, uniformity factor and test weight were the characters affected.

Cultivar assessments changed considerably for each of the three harvest treatments for percent germination. The grouping of genotypes based upon Duncan's Multiple Range values differed for each treatment. Simple correlations between harvest treatments 2 and 3 and the control treatment, although highly significant, were not exceptionally high (variation explained: 17 - 18%). It is interesting to note harvest treatment 2 was positively correlated to treatment 1, while treatment 3 gave a negative correlation value (table 36).

Germination resistance was also subject to genotype x harvest treatment interactions. However, two of the harvest treatments, treatments 1 and 3, produced similar groupings of the six genotypes (table 37). The groupings of cultivars for harvest treatment 2 was unique. These results are further substantiated by the correlation values. Treatment 3 gave the higher correlation value with the control

Table:36 Barley Genotype x Harvest Treatment Interaction Means (averaged over all replicates and samples) and Harvest Treatment Correlation Values (n=48) for Germination (%)

Genotype	Harvest Treatment		
	1	2	3
Olli	97.1 bc[1]	95.7 ab	99.9 a
Gateway 63	95.9 c	90.6 c	99.6 a
Conquest	97.9 ab	92.5 c	98.1 ab
Bonanza	99.0 a	98.2 a	96.3 b
Galt	99.0 a	95.4 b	97.9 ab
Jubilee	99.1 a	96.2 ab	96.5 a
Mean	98.0	94.8	98.0
$r_{1.x}$	1.000	0.427 **[2]	-0.421 **

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

2 ** indicates significance at the 1% level of significance

Table: 37 Barley Genotype x Harvest Treatment Interaction Means (averaged over all replicates and samples) and Harvest Treatment Correlation Values (n=48) for Germination Resistance

Genotype	Harvest Treatment		
	1	2	3
Olli	24.8 b[1]	29.9 c	25.1 b
Gateway 63	25.0 b	33.8 ab	26.3 b
Conquest	24.9 b	31.3 bc	25.9 b
Bonanza	24.8 b	28.5 c	27.4 b
Galt	30.9 a	33.9 ab	33.5 a
Jubilee	31.8 a	35.4 a	31.9 a
Mean	27.0	32.1	28.3
$r_{1.x}$	1.000	0.482 **[2]	0.673 **

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

2 ** indicates significance at the 1% level of significance

method than treatment 2. Both correlation coefficients were highly significant.

Genotype x harvest treatment interactions had a significant influence on the third germination character, uniformity factor. Each treatment gave rise to a unique evaluation of the six barley cultivars by Duncan's Multiple Range test (table 38). Significant differences could not be detected among the genotypes under the control harvest treatment. For treatments 2 and 3, the genotypes were separated into two groups. The correlation of treatment 3 with 1 was nonsignificant and the correlation of harvest treatment 2 with 1, although highly significant, was very low (variation explained: 14%)

Test weight was the fourth character shown to be sensitive to genotype x harvest treatment interactions. Each treatment produced a different grouping or assessment of the six barley cultivars (table 39). Treatment 3 gave the highest correlation with the control harvest treatment. The correlation values for both of the alternate harvesting treatments were highly significant.

Although yield values were not influenced by genotype x harvest treatment interactions, they were sensitive to genotype x harvest treatment x yield measure interactions. Table 40 lists the genotype x harvest treatment x drying interaction means, and table 41 lists the genotype x harvest treatment x moisture adjustment interaction means. For treatment 1, using either wet or dry weights, the six cultivars were separated into three overlapping groups, and for the remaining four treatment combinations the genotypes were nonsignificantly

Table: 38 Barley Genotype x Harvest Treatment Interaction Means (averaged over all replicates and samples) and Harvest Treatment Correlation Values (n=48) for Germination Uniformity Factor

Genotype	Harvest Treatment		
	1	2	3
Olli	11.0 a[1]	14.1 a	10.0 b
Gateway 63	10.7 a	14.9 a	10.0 b
Conquest	10.6 a	13.9 a	13.4 a
Bonanza	9.7 a	11.6 b	14.0 a
Galt	11.2 a	13.1 ab	13.8 a
Jubilee	12.0 a	12.2 b	14.4 a
Mean	10.9	13.3	12.6
$r_{1.x}$	1.000	0.370 **[2]	0.210

1 Means followed by the same letter are not significantly different at the 5% level of dignificance by Duncan's Multiple Range test

2 ** indicates significance at the 1% level of significance

Table: 39 Barley Genotype x Harvest Treatment Interaction Means (averaged over moisture adjustment and replicates) and Harvest Treatment Correlation Values (n=48) for Test Weight (kg/hl)

Genotype	Harvest Treatment		
	1	2	3
Olli	55.4 c[1]	46.9 d	50.6 c
Gateway 63	61.1 a	52.6 a	57.0 a
Conquest	59.0 b	50.6 b	52.4 b
Bonanza	52.3 d	50.0 b	50.6 c
Galt	51.5 d	49.8 b	50.1 c
Jubilee	51.3 d	48.6 c	47.6 d
Mean	55.1	49.8	51.4
$r_{1.x}$	1.000	0.498 **[2]	0.825 **

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

2 ** indicates significance at the 1% level of significance

Table: 40 Barley Genotype x Harvest Treatment x Drying Interaction Means (averaged over moisture adjustment and replicates) for Yield (g/2.3 m^2)

Genotype	Drying					
	Wet Weight			Dry Weight		
	Harvest Treatment					
	1	2	3	1	2	3
Olli	1264 a[1]	1174 a	989 a	890 abc	827 a	818 a
Gateway 63	1368 a	1365 a	921 a	927 abc	984 a	746 a
Conquest	1346 a	1364 a	994 a	1011 a	993 a	762 a
Bonanza	1057 bc	1050 a	1000 a	839 bc	900 a	751 a
Galt	1240 ab	1284 a	1075 a	985 ab	975 a	814 a
Jubilee	1012 c	1150 a	994 a	795 c	871 a	756 a
Mean	1214	1231	995	908	925	775

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

Table: 41 Barley Genotype x Harvest Treatment x Moisture Adjustment Interaction Means (averaged over drying and replicates) for Yield (g/2.3 m^2)

Genotype	Moisture Adjustment					
	Unadjusted Weight			Adjusted Weight		
	Harvest Treatment					
	1	2	3	1	2	3
Olli	1090 a[1]	1019 bc	845 a	1063 abc	982 a	962 a
Gateway 63	1190 a	1221 a	778 a	1105 abc	1127 a	889 a
Conquest	1149 a	1153 ab	845 a	1207 a	1204 a	910 a
Bonanza	898 bc	924 c	850 a	998 bc	1026 a	901 a
Galt	1058 ab	1070 abc	911 a	1168 ab	1189 a	978 a
Jubilee	865 c	964 c	851 a	943 c	1056 a	899 a
Mean	1042	1058	847	1081	1097	923

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

different (table 40). For the second set of second order interaction means, genotype x harvest treatment x moisture adjustment means, three of the six treatment combinations gave rise to significant genotypic differences by analysis of variance (table 41). These treatments were harvest treatment 1, with unadjusted and with adjusted weights, and harvest treatment 2, with unadjusted weights. Table 42 lists the third order interaction means. For most treatment combinations (seven of twelve), it was not possible to distinguish among the genotypic means by analysis of variance. The treatment combinations for which significant differences among the six genotypic means were found, were harvest treatment 1, using wet, unadjusted; dry, unadjusted and dry, adjusted weights; and treatments 1 and 2 , using wet, unadjusted weights. Classification of genotypic means using Duncan's Multiple Range test was identical for the former three harvest treatment combinations. This result was not unexpected as two of the alternate treatment combination yield values were derived from the control treatment combination values. The latter two treatment combinations each gave rise to a unique grouping of the genotype means for the character yield. Simple correlation coefficient values were also calculated to provide some measure of the relation between different harvest treatment combinations. Simple correlation values between harvest treatment 1, using dry, unadjusted yield values (the control method currently in use) and each of the other harvest treatments produced similar results (table 42).

Table: 42 Barley Genotype x Harvest Treatment x Drying x Moisture Adjustment Interaction Means (averaged over replicates) for Yield (g/2.3 m^2)

Genotype	Drying											
	Wet Weight						Dry Weight					
	Moisture Adjustment											
	Unadjusted Weight			Adjusted Weight			Unadjusted Weight			Adjusted Weight		
	Harvest Treatment											
	1	2	3	1	2	3	1	2	3	1	2	3
Olli	1294 ab[1]	1201 bc	878 a	1235 abc	1147 a	1100 a	888 abc	836 a	813 a	892 abc	818 a	824 a
Gateway 63	1452 a	1449 a	806 a	1284 abc	1280 a	1036 a	928 abc	993 a	750 a	927 abc	974 a	742 a
Conquest	1290 ab	1307 ab	928 a	1402 a	1422 a	1060 a	1009 a	999 a	762 a	1012 a	986 a	761 a
Bonanza	955 cd	949 d	949 a	1159 bc	1151 a	1051 a	841 bc	900 a	752 a	837 bc	900 a	751 a
Galt	1125 bc	1162 bc	1007 a	1356 ab	1405 a	1143 a	992 ab	978 a	815 a	979 ab	972 a	812 a
Jubilee	930 d	1054 cd	946 a	1095 c	1245 a	1042 a	800 c	874 a	757 a	791 c	868 a	756 a
$r_{DU1.x}$	0.680**[2]	0.486*	-0.049	0.998**	0.576**	0.014	1.000	0.663**	0.019	0.998**	0.658**	0.032

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

2 *, ** indicate significance at the 5% and 1% levels of significance respectively

The control treatment combination was highly correlated with those treatments producing similar groupings of the six genotypes. The correlation values with harvest treatment 2 were of intermediate value and those with harvest treatment 3 were nonsignificant for each of the four yield measures.

From table 43, each of the yield measures, drying and moisture adjustment, and their interaction term had a significant influence on yield values. Wet weight values were significantly higher than dry weights, as would be expected (table 43). Unadjusted weights were significantly lower than adjusted weights (table 43). Of the interaction means, wet, adjusted weights were the highest; wet, unadjusted values were intermediate; and the dry, unadjusted and dry, adjusted weights were low and indistinguishable (table 43).

II. Maturity Assessments

A. Maturity Measures

1. Wheat

Five methods of measuring maturity, including three measures currently employed, were compared. These measures were (1) days from seeding to 35%mcwb, the control method, (2) days from seeding to heading, (3) field rating, (4) Delmhorst G-6c reading of moisture content, and (5) days from seeding to swathing ripeness.

Highly significant differences among the seven wheat genotypes were found for each of the five measures of maturity (table 44). However for each measure a different ranking of the wheat genotypes, based upon

Table: 43 Drying x Moisture Adjustment Interaction Means (averaged over genotypes, harvest treatments and replicates) for Yield (g/2.3 m^2) from the Barley Harvesting Methodology Test

Moisture Adjustment	Drying		Mean
	Wet Weight	Dry Weight	
Unadjusted Weight	1093 b[1]	871 c	982
Adjusted Weight	1201 a	867 c	1034
Mean	1147	869	1008

1 Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

Table: 44 Analysis of Variance Table for Five Maturity Characters of the Wheat Maturity Assessment Test

Source of Variation	Degrees of Freedom	Mean Squares				
		Days to 35% mcwb	Days to Heading	Field Rating	Delmhorst G-6c	Days to Swathing Ripeness
Replicate	3	11.1	0.6	0.1	1.7	0.4
Genotype	6	58.0 **[1]	43.9 **	17.2***	31.3 **	39.7 **
Error	18	1.5	0.3	0.6	5.2	0.4
Coefficient of Variation (%)		1.1	0.9	14.2	9.5	0.5

[1] ** indicates significance at the 1% level of significance

Duncan's Multiple Range values, was produced (table 45).

Correlations between the five measures of maturity are given in table 46. Days from seeding to swathing ripeness gave the highest, and Delmhorst G-6c reading gave the lowest correlations with the control method. The measures field rating of relative maturity demonstrated its highest correlation with days from seeding to heading. The Delmhorst G-6c reading was more highly correlated with days from seeding to swathing ripeness than any other variable.

A second test of the Delmhorst G-6c moisture meter was made in conjunction with standard air-oven moisture determinations. Correlation between the two sets of moisture content determinations was highly significant (r_{xy}=0.936, n=174). However, comparison of the mean values from the two sets of determinations using a t-test showed the means to be highly significantly different (t=4.45, n=174).

Although it appears that moisture meter readings may be adequete for obtaining objective relative assessments of maturity, it must also be possible to reliably distinguish among experimental lines according to maturity. Figure 4 presents the drying curves for each of the seven wheat cultivars, as well as the results of analysis of variance testing at each sampling date. Highly significant differences among the genotypes could be detected at the early sampling dates, during maturation and ripening. As most of the cultivars approached equilibrium with the atmospheric moisture differences among their means became very small and for some sampling dates nonsignificant. From graph 4 , it is clear that the late cultivars, Glenlea and Pitic 62, have the highest moisture contents, and Park, the earliest genotype, the lowest values at any given sampling date prior to the attainment of physiological

Table: 45 Means of Seven Wheat Genotypes (averaged over all replicates) for Five Maturity Parameters

Genotype	Maturity Parameter									
	Days from Seeding to 35% mcwb		Days from Seeding to Heading		Field Rating (1-9)		Delmhorst G-6c (% mcwb)		Days from Seeding to Swathing Ripeness	
Park	104.2	c[1]	55.0	e	8.5	a	20.8	c	108.0	d
Neepawa	107.8	b	59.8	c	7.0	b	25.4	b	112.0	b
Norquay	106.8	b	59.2	c	5.0	cd	24.1	bc	108.5	cd
Glenlea	114.0	a	61.2	b	4.0	d	29.0	a	115.0	a
Pitic 62	113.5	a	65.0	a	2.2	e	25.4	b	115.0	a
70M009002	106.2	b	59.5	c	5.5	c	21.8	bc	109.0	c
70M110001	106.2	b	56.0	d	6.8	b	22.4	bc	108.2	cd
Mean	108.4		59.4		5.6		24.1		110.8	

[1] Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range test

Table: 46 Simple Correlation Coefficients Between Five Maturity Parameters measured in Wheat (n=28)

Maturity Measure	Days from Seeding to 35% mcwb	Days from Seeding to Heading	Field Rating	Delmhorst G-6c Reading
Days from Seeding to Heading	0.805[1]			
Field Rating	-0.777	-0.875		
Delmhorst G-6c Reading	0.669	0.510	-0.527	
Days from Seeding to Swathing Ripeness	0.892	0.825	-0.709	0.707

[1] All values significant at the 1% level of significance

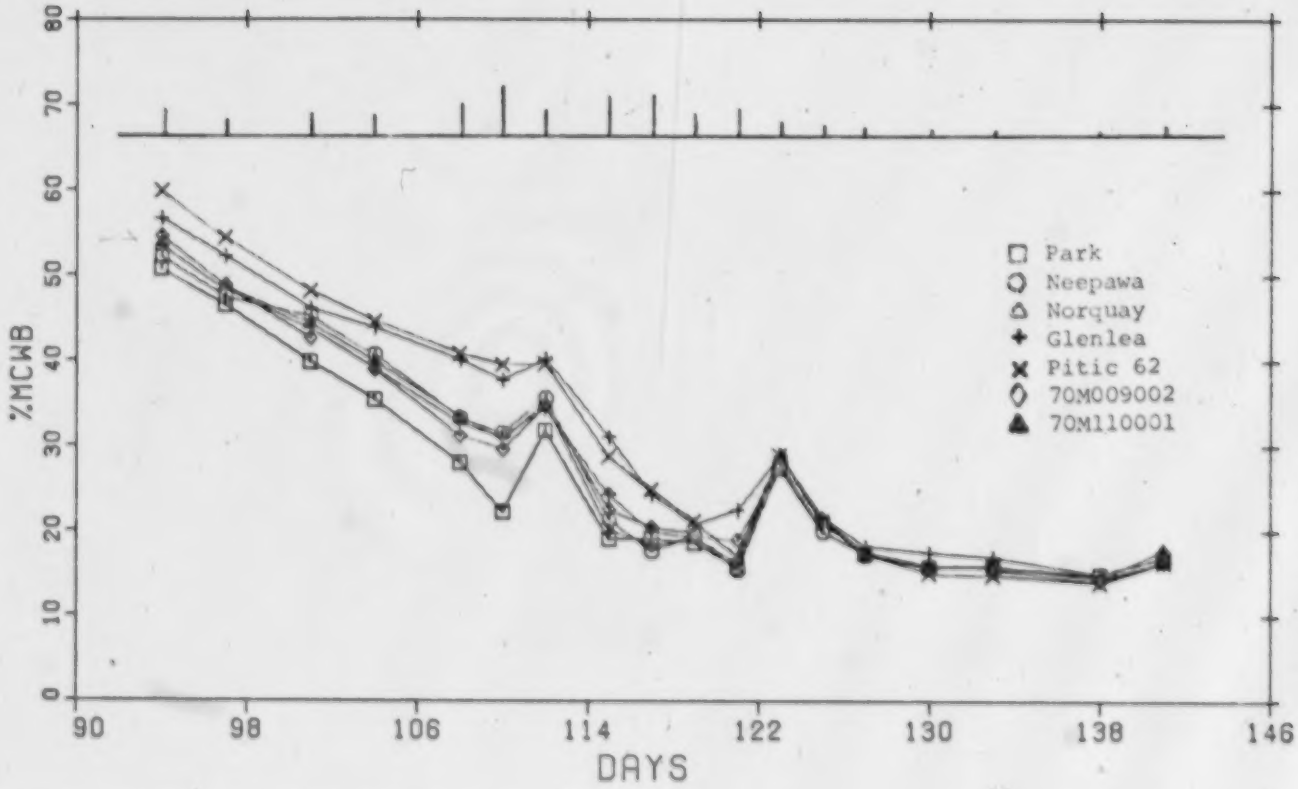

Figure: 4 Drying Curves for Seven Wheat Genotypes. %mcwb represents moisture content-wet basis, and days represents days from seeding. Inserted vertical bar graph gives least significant difference values (5% level) for each sampling date.

maturity of the cultivars. The remaining genotypes generally have indistinguishable intermediate values. This broad classification of the seven genotypes into early, intermediate and late maturity is consistent with the ordering of the cultivars for days to 35%mcwb. At the earliest sampling dates, those prior to 101 days from seeding, however, the moisture content of Park was indistinguishable from some of those of intermediate maturity, like Neepawa and 70M110001. At the sampling date, 104 days from seeding, a good reliable assessment of relative maturities of the seven cultivars was obtained. This suggests that sampling experimental lines of a range of maturities for moisture content on one date is possible. Very early sampling of the lines is not as desireable as later sampling. Sampling when the earliest cultivar has reached physiological maturity appears to be a suitable time for assessing relative maturities on the basis of moisture content. When sampling is done later in the growing season, differences among the cultivars become nonsignificant and the ordering of the genotypes is altered. For example, at 130 days from seeding, highly significant differences could be found among genotypes for moisture content, but Glenlea had the highest and Pitic 62 the lowest values. The remaining five genotypes had similar, nondistinct mean values, different from either Glenlea or Pitic 62. The relative maturities of the genotypes at this date would be inaccurate and misleading.

2. Barley

The procedures used for maturity assessments in barley were very similar to those employed in the wheat experiment. Highly significant differences among the six genotypes were found for four of the five measures of maturity (table 47). Days from seeding to swathing

Table: 47 Analysis of Variance Table for Four Maturity Characters of the Barley Maturity Assessment Test

Source of Variation	Degrees of Freedom	Mean Squares			
		Days to 35% mcwb	Days to Heading	Field Rating	Delmhorst Reading
Replicate	3	0.7	0.1	0.8	7.0
Genotype	5	10.0 **[1]	26.6 **	28.5 **	30.6 **
Error	15	0.5	0.1	0.3	5.6
Coefficient of Variation (%)		0.7	0.4	8.6	10.9

[1] ** indicates significance at the 1% level of significance

was not subjected to analysis of variance because no variation in the genotypes was recorded over the four replicates. Olli was consistently the earliest cultivar and Galt and Jubilee the latest cultivars. The remaining three genotypes were of intermediate maturity (table 48). However, specific groupings based upon Duncan's Multiple Range values of the six cultivars differed for each maturity measure (table 48). None of the alternate measures were able to reproduce the grouping of the control measure, days from seeding to 35%mcwb. The simple correlations between the five sets of maturity determinations are given in table 49. Field rating gave the highest correlation value with days from seeding to 35%mcwb, and Delmhorst G-6c reading the lowest. Correlation values between the control method and days from seeding to heading, and days from seeding to swathing ripeness were also high. The field rating assessments were more closely correlated with days to swathing ripeness than days to heading, in contrast to the results in the wheat test. The Delmhorst G-6c reading exhibited its highest correlation with days from seeding to swathing ripeness also.

In a second test of the Delmhorst G-6c moisture meter, moisture contents from the dielectric meter were compared to standard air-oven determinations made on the same samples of grain using simple correlation and a t-test. A highly significant correlation between the Delmhorst G-6c readings and standard moisture content values was found. (r_{xy}=0.928, n=213). Parallel to the results from wheat, highly significant differences were displayed between the mean values of the two measures of moisture content (t=7.88, n=213). The standard moisture content determinations had a mean value substantially greater than the mean of the Delmhorst G-6c readings.

Table: 48 Means of Six Barley Genotypes (averaged over all replicates) for Five Maturity Parameters

Genotype	Maturity Parameters									
	Days from Seeding to 35% mcwb		Days from Seeding to Heading		Field Rating (1-9)		Delmhorst G-6c (% mcwb)		Days from Seeding to Swathing Ripeness	
Olli	93.8	c[1]	54.0	d	9.0	a	18.0	c	90	
Gateway 63	96.2	b	56.0	c	7.8	b	20.0	bc	94	
Conquest	96.0	b	59.0	b	7.5	b	20.8	bc	97	
Bonanza	96.5	b	59.0	b	5.5	c	22.1	ab	101	
Galt	97.8	a	59.5	b	2.8	d	25.8	a	101	
Jubilee	98.2	a	61.0	a	2.8	d	23.8	ab	101	
Mean	96.4		58.1		5.9		21.7		97.3	

[1] Means followed by the same letter are not significantly different at the 5% level of significance by Duncan's Multiple Range Test

Table: 49 Simple Correlation Coefficients Between Five Maturity Parameters measured in Barley (n=24)

Maturity Parameter	Days from Seeding to 35% mcwb	Days from Seeding to Heading	Field Rating	Delmhorst G-6c Reading
Days from Seeding to Heading	0.818[1]			
Field Rating	-0.824	-0.828		
Delmhorst G-6c Reading	0.637	0.651	-0.721	
Days from Seeding to Swathing Ripeness	0.810	0.940	-0.863	0.691

[1] All values significant at the 1% level of significance

The concern of when sampling of the genotypes for moisture content can be conducted with the condition that relative assessments of maturity be reliable and consistent with expectations is important to the applicability of this method of maturity assessment. Figure 5 illustrates the drying curves of each of the six barley cultivars and the results of analysis of variance at each sampling date. Significant differences among the genotypic means disappear when most of the cultivars have completed ripening. Only in the range of about 52%mcwb to 18%mcwb (average of all cultivars and replicates) could significant differences for moisture content be detected among the six cultivars. For the earliest and the later dates in which significant differences could be found, the genotypes could not be classified into early, intermediate and late maturity classes consistent with expectations of what is known of these six cultivars. Sampling when the earliest genotype has achieved physiological maturity can be recommended as a suitable time for assessing relative maturities using moisture content values. A similar result was found in wheat.

B. Drying Curves

1. Wheat

A study of the nature of the drying curves of five wheat cultivars and two experimental lines was initiated. The basis for the analysis was the model of drying in cereal grains proposed by Meredith and Jenkins (1975). These authors suggested that the drying process was basically an active physiological process whereby metabolic moisture is removed from the caryopsis. Environmentally added moisture, the authors suggested, is removed passively by evaporation.

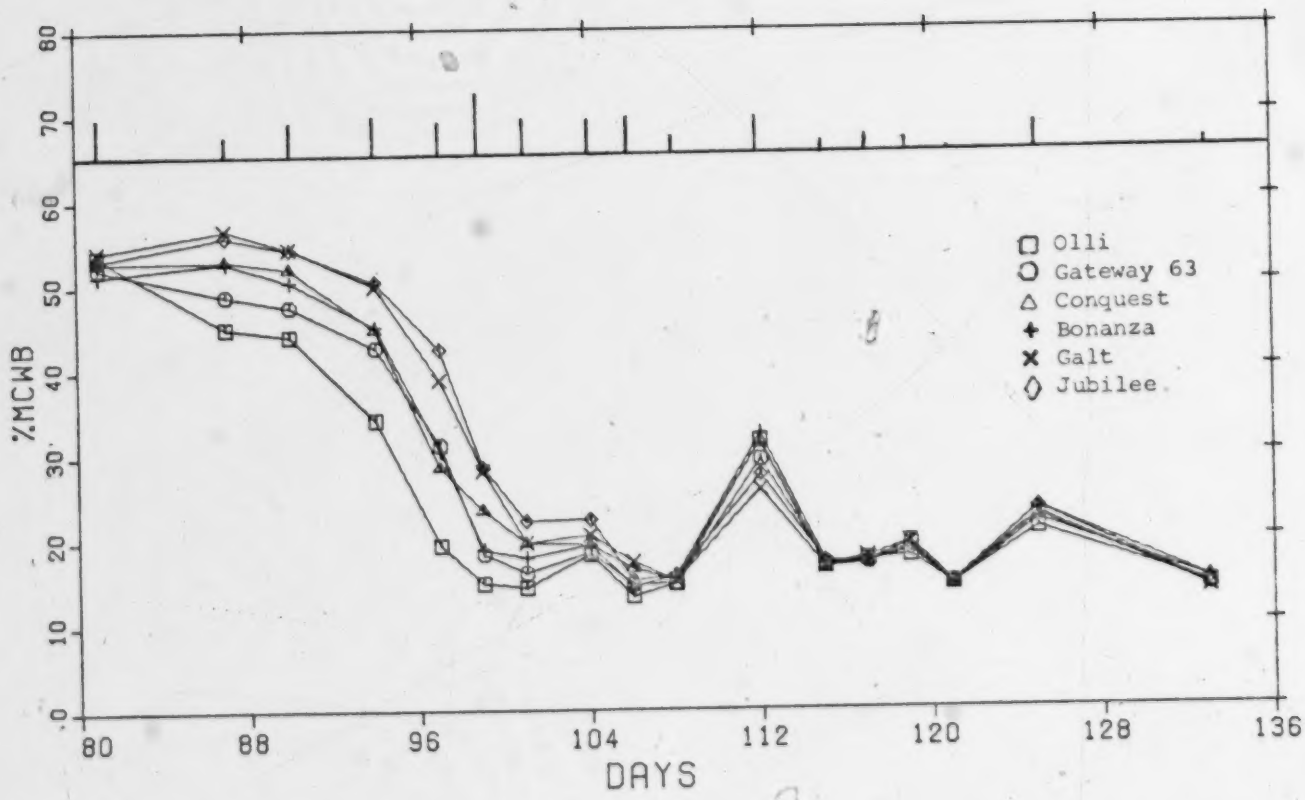

Figure: 5 Drying Curves for Six Barley Genotypes. %mcwb represents moisture content-wet basis, and days represents days from seeding. Inserted vertical bar graph gives least significant difference values (5% level) for each sampling date.

The first step of the analysis of the drying curves was the description of the basic underlying drying rate. A regression analysis approach, relating moisture contents to days from seeding was utilized. Several models were tested (table 50). These included simple linear regression, polynomial regression and multiple regression models. Both wet and dry based moisture contents were tested and compared. In addition, reciprocal transformations of both %mcwb and %mcdb values were analyzed in an attempt to remove a curvilinear trend from the data points (Sokal and Rohlf, 1969).

The initial analysis was conducted on the full set of data points, including moisture contents of all seven genotypes and all four replicates. Table 50 lists the results from the overall regression analyses. A significant amount of the variation from the mean could be explained be the regression in all cases tested. From table 50, a significant lack of fit (Draper and Smith, 1966) was demonstrated for each analysis of the data. It is assumed that deviations from the fitted regression curves were due principally to environmentally added moisture. In a later section, deviations from the estimated drying curves are related to fluctuations in various weather parameters, thereby, formalizing the influence of weather upon the drying process. Using the value percent variation explained, the %mcwb and %mcdb data could be fitted with either a polynomial or a multiple regression model equally well. Simple regression models gave a poor fit of the data. Little improvement of fit was obtained over the simple linear regression analysis be applying the multiple regression procedure to the reciprocally transformed data sets. Only for the simple regression analysis did the use of reciprocal values improve the fit over the use of the

Table: 50 Summary of Results of Regression Analyses on Wheat Drying Curves (based on the complete data set)

Type of Regression	Model	Variables	Equation	Mean Square Regression	Mean Square LOF[1]	Variation Explained (%)
Simple	$Y=b_0+b_1X+e$	Y=%mcwb X=days from seeding	Y= 127.6 -0.85 X	63943 **[2]	727 **	74.4
		Y=%mcdb X=days from seeding	Y= 276.2 -1.98 X	346849 **	5703 **	73.8
		Y=reciprocal %mcwb X=days from seeding	Y= -8.97 +0.11 X	1134 **	12 **	79.1
		Y=reciprocal %mcdb X=days from seeding	Y= -9.97 +0.11 X	1134 **	12 **	79.1
Polynomial	$Y=b_0+b_1X+b_2X^2+b_3X^3+e$	Y=%mcwb X=days from seeding	Y= 179.8 +0.16 X -0.03 X^2	23647 **		88.1
		Y=%mcdb X=days from seeding	Y= 2694.1 -57.08 X -0.41 X^2 -0.001 X^3	140931 **		89.9
Multiple	$Y=b_0+b_1X_1+b_2X_2+b_3X_3+e$	Y=%mcwb X_1,X_2,X_3=dummy variables	Y= 59.85 -4.57 X_1 -1.60 X_2	22938 **	483 **	85.5
		Y=%mcdb X_1,X_2,X_3=dummy variables	Y= 138.4 -14.10 X_1 -2.91 X_2 +4.50 X_3	138110 **	1697 **	88.1
		Y=reciprocal %mcwb X_1,X_2,X_3=dummy variables	Y= 1.49 ~~+0.~~25 X_1 +0.29 X_2 +0.22 X_3	379 **	14 **	79.2
		Y=reciprocal %mcdb X_1,X_2,X_3=dummy variables	Y= 0.49 +0.25 X_1 +0.29 X_2 +0.22 X_3	379 **	14 **	79.2

1 Mean Squares due to Lack of Fit

2 ** indicates significance at the 1% level of significance

nontransformed data points. Because the multiple regression approach supplies some means of quantifying various aspects of the drying curve in a meaningful biological manner, unlike the polynomial regression, the former was used to continue analysis and comparisons of the drying curves of the seven wheat genotypes.

A second consideration was the type of moisture value to be used for analysis. Values expressed on a dry weight basis were selected over those expressed on a wet weight basis for two reasons. The fit for the overall data analysis using the multiple regression model was slightly superior using the %mcdb data set. Expression of moisture contents on a dry weight basis is more sound theoretically when relating changes in the proportion of moisture in the kernels. Moisture contents expressed on a wet weight basis are more common in commerce than research.

Multiple regression analysis was applied to moisture contents collected for each genotype. A good fit was found for each of the five cultivars and two experimental lines (table 51, and figures 6, 7, 8, 9, 10, 11 and 12). In all seven cases a highly significant mean square due to regression was found. The percent variation explained was greater than 90% for all genotypes. Comparison of the regression coefficients by analysis of variance and Duncan's Multiple Range test indicated highly significant differences could be detected among the seven genotypes. The two latest cultivars, Glenlea and Pitic 62, had the highest b_0 values; while, Park, the earliest cultivar had the lowest mean b_0 value. This suggests that Park had experienced the most drying, and Pitic 62 and Glenlea the least drying at the initiation of sampling.

Significant differences in the rate of drying, as quantified by the b_1 regression coefficient, were detected. The latest cultivar,

Table: 51 Summary of the Results of Multiple Regression Analysis of the Drying Curves of Seven Wheat Genotypes

Genotype	Regression Coefficients				Mean Square Regression	Mean Square LOF[1]	Variation Explained (%)
	b_0	b_1	b_2	b_3			
Park	115.1 d[2]	-12.81 **[3] ab	-1.53 ** a	0.98 ns b	13595 **	174 **	93.0
Neepawa	122.3 cd	-12.45 ** a	-2.72 ** b	1.57 ns b	17006 **	324 **	90.3
Norquay	127.0 c	-13.46 ** abc	-2.51 ** b	2.00 ns b	17872 **	307 **	91.1
Glenlea	143.5 b	-14.69 ** c	-4.27 ** c	9.71 ** a	24258 **	285 **	93.6
Pitic 62	162.7 a	-17.91 ** d	-4.55 ** c	11.35 ** a	32456 **	370 **	93.2
70M009002	130.2 c	-14.16 ** bc	-2.43 ** b	2.53 ns b	18675 **	195 **	91.9
70M110001	126.3 c	-13.42 ** abc	-2.65 ** b	3.50 ns b	17584 **	220 **	92.7

1 Mean Squares due to Lack of Fit

2 Means followed by the same letter do not differ significantly at the 5% level of significance by Duncan's Multiple Range test

3 ** indicates significance at the 5% level of significance

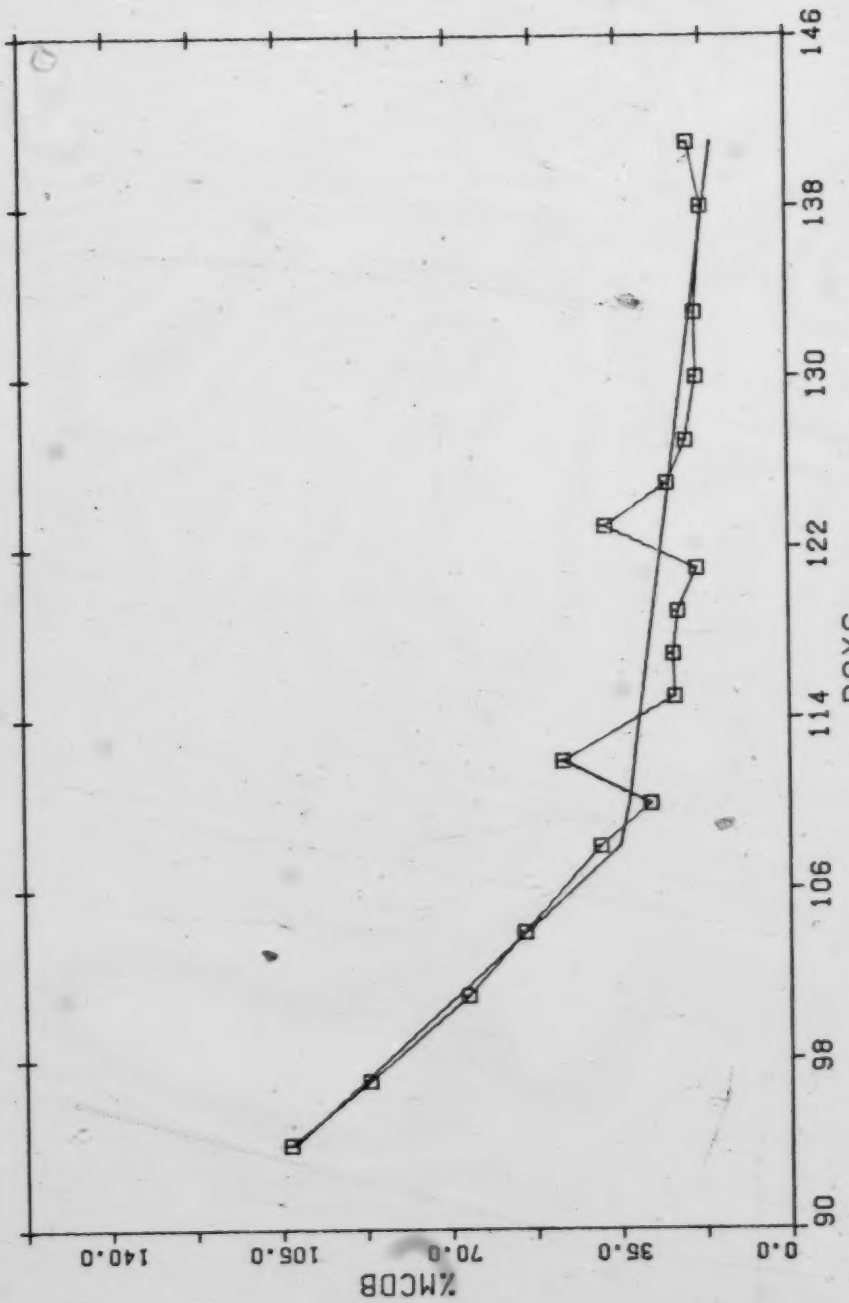

Figure: 6 Drying Curve and Fitted Multiple Regression Curve for Park. %mcdb represents moisture content-dry basis, and days represents days from seeding.

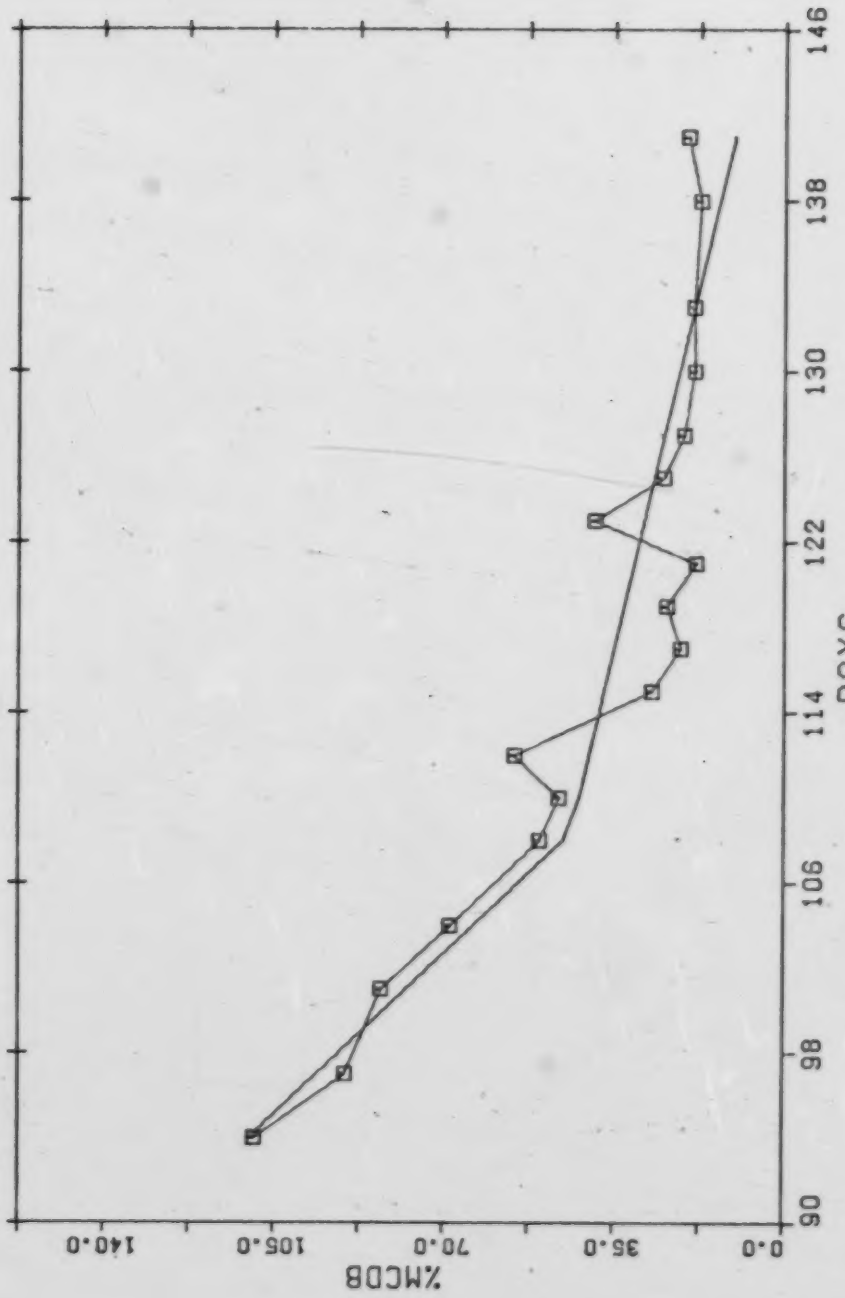

Figure: 7 Drying Curve and Fitted Multiple Regression Curve for Neepawa. %mcdb represents moisture content-dry basis, and days represents days from seeding.

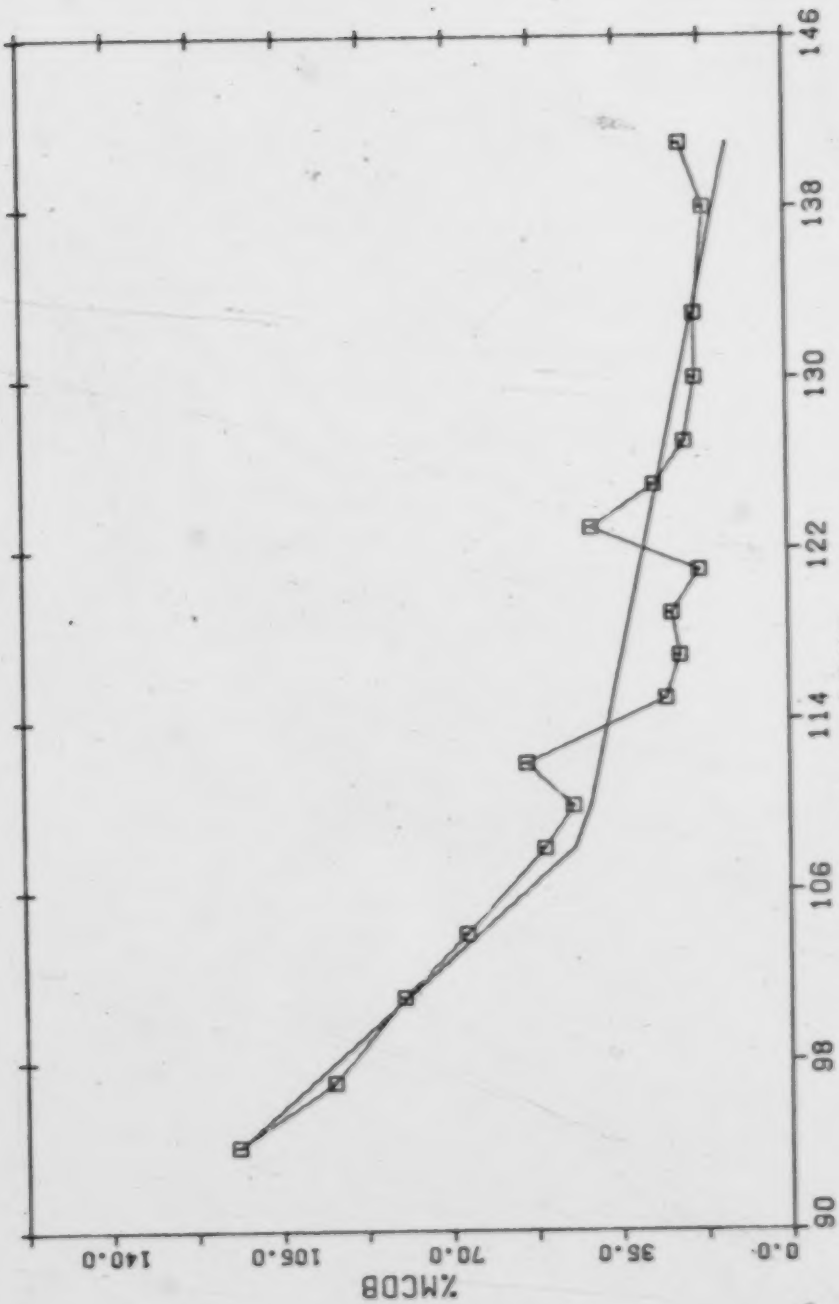

Figure: 8 Drying Curve and Fitted Multiple Regression Curve for Norquay. %mcdb represents moisture content-dry basis, and days represents days from seeding.

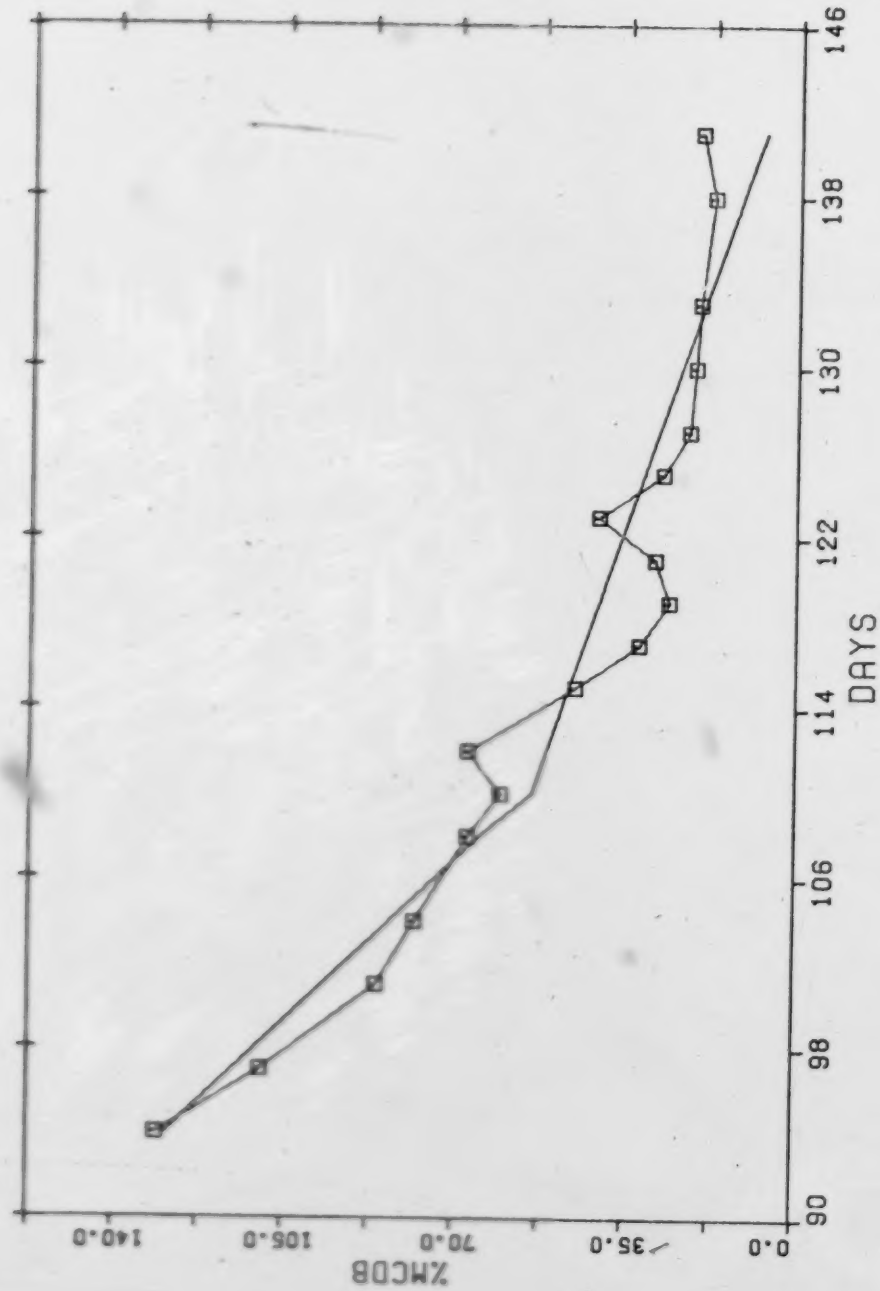

Figure: 9 Drying Curve and Fitted Multiple Regression Curve for Glenlea. %mcdb represents moisture content-dry basis, and days represents days from seeding.

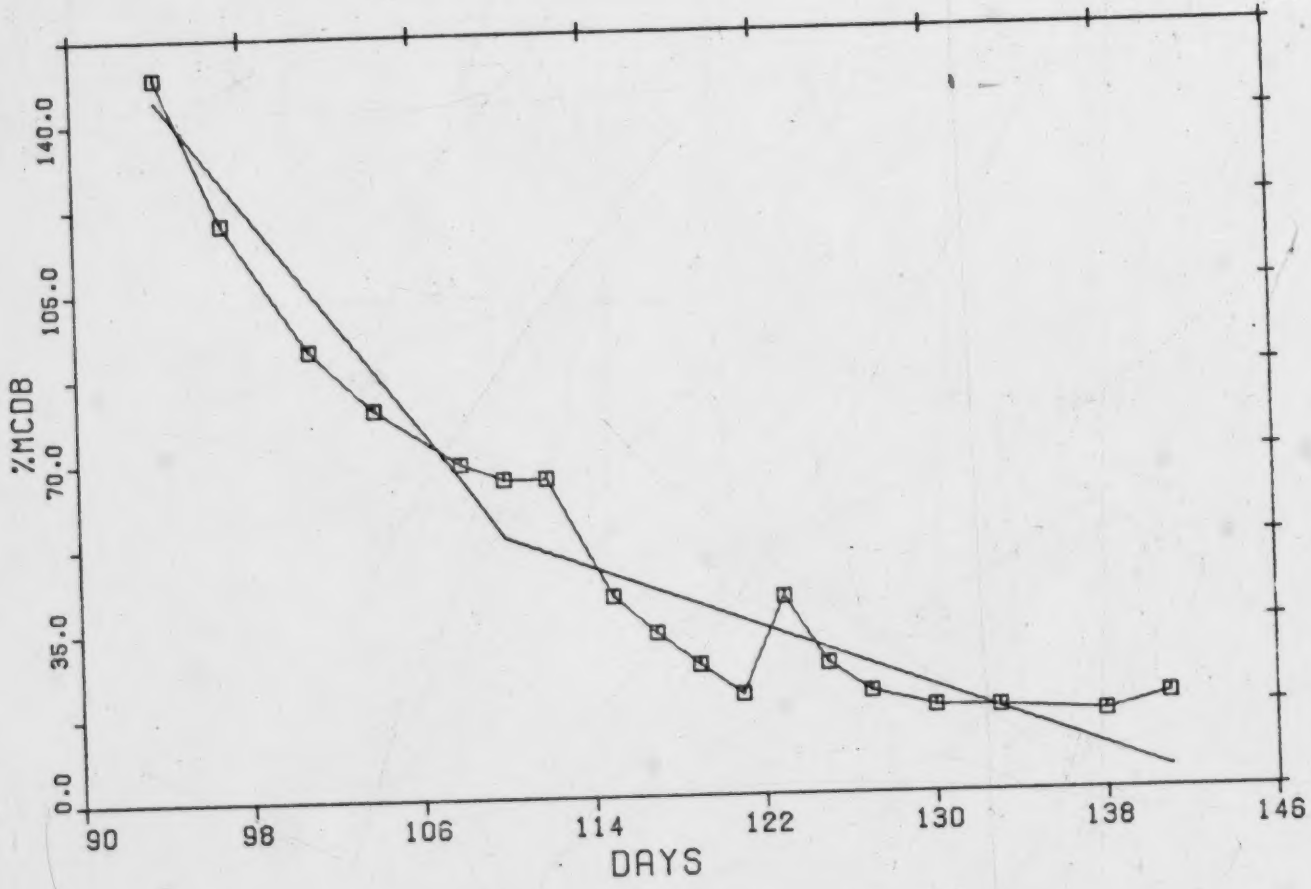

Figure: 10 Drying Curve and Fitted Multiple Regression Curve for Pitic 62. %mcdb represents moisture content-dry basis, and days represents days from seeding.

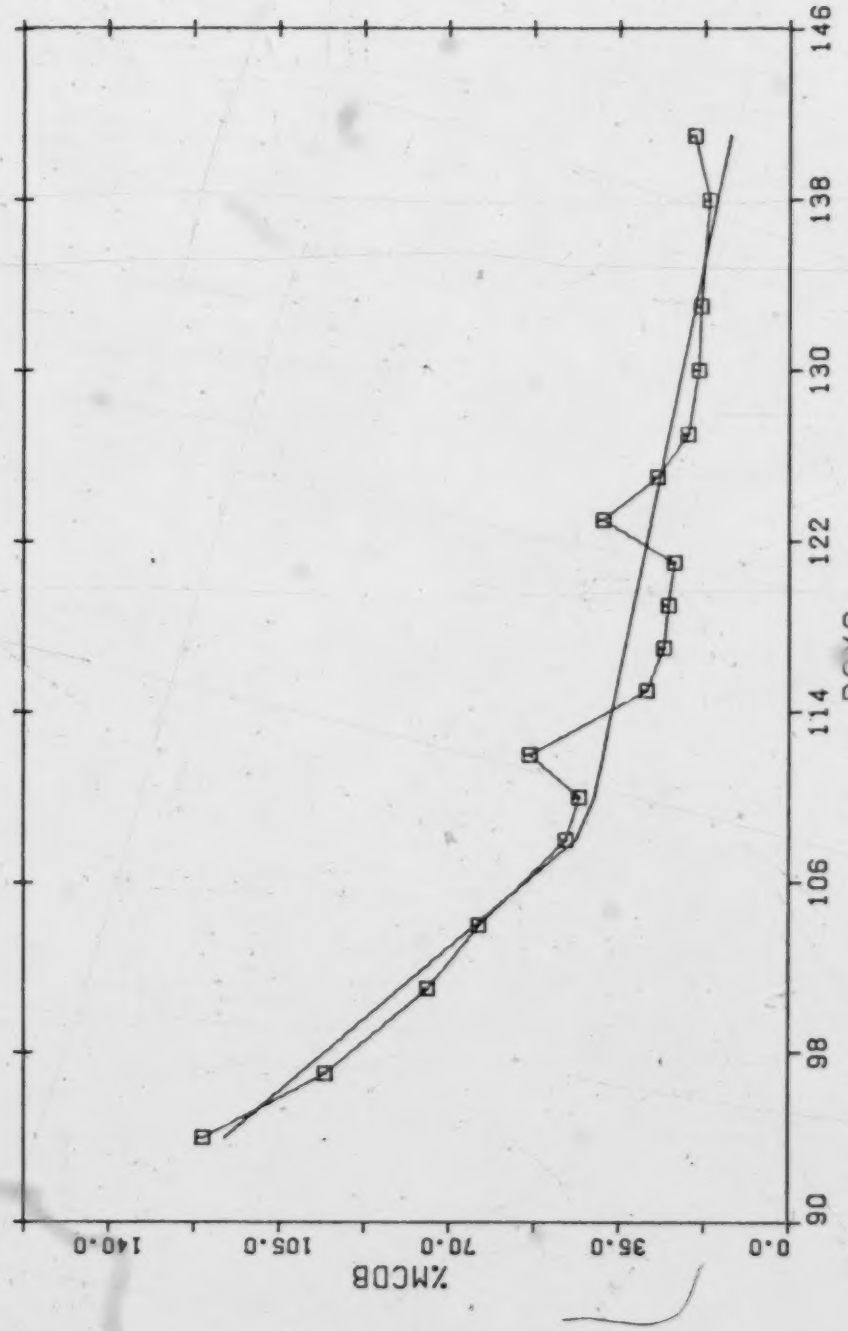

Figure: 11 Drying Curve and Fitted Multiple Regression Curve for 70M009002. %mcdb represents moisture content-dry basis, and days represents days from seeding.

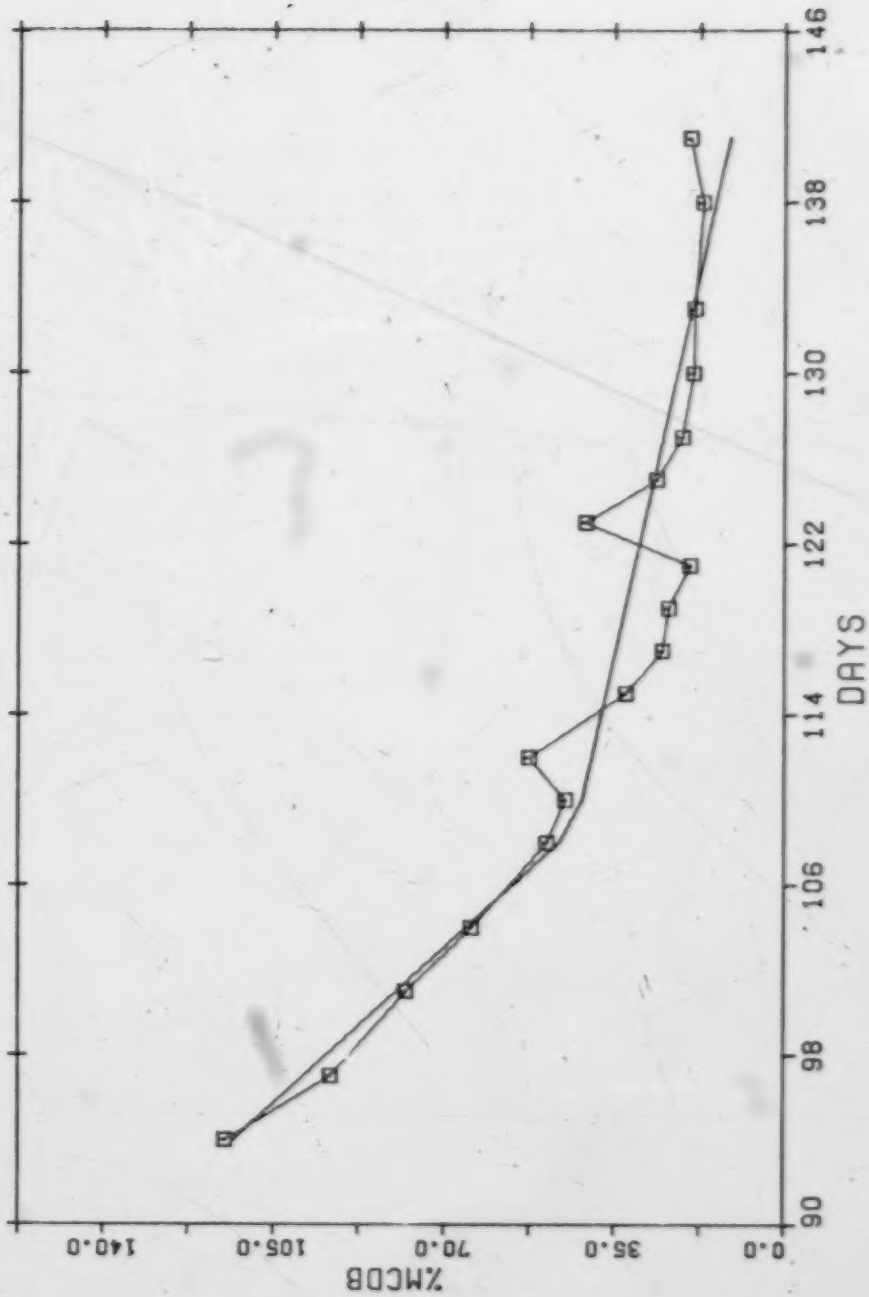

Figure: 12 Drying Curve and Fitted Multiple Regression Curve for 70M110001. %mcdb represents moisture content-dry basis, and days represents days from seeding.

Pitic 62 exhibited the fastest drying rate. Neepawa, a cultivar of intermediate maturity, had the slowest drying rate. The drying rates of Park, Norquay and 70M110001 were also low and indistinguishable from that of Neepawa (table 51).

The slope of the second line, as represented by b_2, was small, negative and significant for each genotype, contrary to expectations (table 51). The genotypes continued to lose moisture at a reduced rate after the initial drying period was completed.

The final regression coefficient, b_3, describes the position of the two lines relative to one another. The mean b_3 values separated into two distinct groups. For the two late cultivars, the b_3 values differed significantly from zero. The remaining five genotypes fell into a second group, characterized by b_3 values nonsignificantly different from zero. The two late cultivars switched from the first to the second drying rate much later than the other five genotypes (table 51).

The second part of the analysis of drying curves was to develop a method of describing the influence of various weather parameters upon the nature of the drying curves. A regression analysis approach was also used for this section of the analysis. In keeping with the model of Meredith and Jenkins (1975), the residuals or variation unexplained by regression on time, were used for this purpose. Both simple and multiple regressions were employed to relate deviations from the drying curves to various weather parameters for each cultivar.

Prior to running the regression analyses, simple correlations between the weather parameters and the overall %mcdb residuals were obtained (table 52). From this set of variables, ten parameters showing the highest correlation values with the residuals were selected. These

Table: 52 Simple Correlations Between Several Weather Parameters and Wheat Drying Curve Residuals (n=504)

Weather Parameter	Days from Sampling					
	0	-1	-2	-3	-4	-5
DGD	-0.153 **[1]	-0.204 **	0.001	0.170 **	0.061	0.039
MXT	-0.224 **	-0.278 **	-0.116 **	0.241 **	0.112 *	0.081
MNT	-0.0	-0.024	0.134 **	0.016	-0.017	-0.031
GRS	0.006	0.037	0.120 **	-0.041	-0.116 **	-0.138 **
DEW	-0.093 *	-0.156 **	0.208 **	0.076	0.073	-0.172 **
RH	0.021	0.177 **	0.287 **	-0.157 **	-0.076	-0.204 **
PPT	-0.171 **	0.434 **	0.312 **	0.040	-0.245 **	-0.173 **
DWS	-0.035	0.298 **	0.125 **	-0.100 *	-0.325 **	-0.069
WSA	-0.012	-0.011	-0.022	-0.027	-0.024	-0.012
MXW	-0.121 **	-0.320 **	-0.072	0.151 **	0.107 *	0.018
MNW	-0.096 *	-0.093 *	-0.050	0.149 **	0.089 *	0.033
EVP	0.100 *	-0.377 **	-0.199 **	0.063	0.189 **	0.096*
COS	0.143 **	-0.396 **	-0.084	-0.130 **	0.115 **	0.060
LGL	0.014	-0.419 **	-0.233 **	-0.062	0.059	0.095 *
BRS	0.094 *	-0.395 **	-0.247 **	-0.057	0.139 **	0.122 **

1 *, ** indicate significance at the 5% and 1% levels of significance respectively

variables are:

1. precipitation at -1 days (mm) PPT-1
2. solar radiation at -1 days (lgl) LGL-1
3. cloud cover rating at -1 days COS-1
4. bright sunshine at -1 days (h) BRS-1
5. evaporation at -1 days (in) EVP-1
6. daily wind run at -4 days (miles) DWS-4
7. maximum wind speed at -1 days (miles/h) MXW-1
8. precipitation at -2 days (mm) PPT-2
9. daily wind run at -1 days (miles) DWS-1
10. relative humidity at -2 days (%) RH-2

All ten variables were highly significantly correlated with the residuals. As might be expected, variables from the day prior to sampling demonstrated the closest correlations with the residuals. The residuals for each genotype were sorted according to an ascending order of nine of the ten variables, with the exception of cloud cover rating. This variable, because it existed in only bivariate form, proved unsuited for regression analysis.

Simple regressions between the sorted residuals for each cultivar and each weather parameter were made. Table 53 lists the results of the three best fitting regressions for each cultivar. For most genotypes the variables precipitation at -1 days and solar radiation at -1 days provided the best fitting simple regressions for the residuals. However, use of one weather parameter does not fully describe fluctuations in the residuals as evidenced by significant lack of fit values and low values of percent variation explained.

Table: 53 Summary of Simple Linear Regression Analysis of the Drying Curve Residuals for Seven Wheat Genotypes

Genotype	Weather Parameter	Regression Coefficient		Mean Square Regression	Mean Square LOF[1]	Variation Explained (%)
		b_0	b_1			
Park	PPT-1	-2.00	1.97 **[2]	1386 **	36 **	45.0
	LGL-1	15.77	-0.001 **	1214 **	76 **	39.4
	EVP-1	10.11	-10.49 **	1112 **	55 **	36.1
Neepawa	LGL-1	17.79	-0.002 **	1544 **	187 **	28.1
	PPT-1	-2.06	2.02 **	1461 **	126 **	26.6
	DWS-4	7.94	-0.12 **	1262 **	203 **	23.0
Norquay	LGL-1	18.35	-0.002 **	1643 **	166 **	31.3
	PPT-1	-2.11	2.08 **	1543 **	108 **	29.4
	DWS-4	8.29	-0.13 **	1379 **	180 **	26.3
Glenlea	PPT-1	-2.12	2.08 **	1550 **	104 **	31.2
	BRS-1	9.02	-1.10 **	1219 **	173 **	24.6
	LGL-1	15.59	-0.001 **	1186 **	175 **	23.9
Pitic 62	PPT-1	-2.21	2.18 **	1692 **	148 **	24.0
	LGL-1	18.07	-0.002 **	1593 **	224 **	22.6
	BRS-1	10.08	-1.22 **	1524 **	228 **	21.6
70M009002	PPT-1	-2.14	2.10 **	1581 **	47 **	31.9
	EVP-1	11.11	-11.53 **	1344 **	67 **	27.1
	BRS-1	9.37	-1.14 **	1317 **	88 *	26.6
70M110001	LGL-1	16.79	-0.002 **	1375 **	106 **	32.9
	PPT-1	-1.95	1.92 **	1318 **	72 **	31.5
	BRS-1	9.05	-1.10 **	1227 **	116 **	29.3

1 Mean Squares due to Lack of Fit
2 *, ** indicate significance at the 5% and 1% levels of significance respectively

Multiple regression analysis was used to relate the variation of the residuals generated from the drying curves (based upon %mcdb values) of each genotype to the fluctuations of several weather parameters. Simple correlations among the weather parameters were calculated (table 54). Most of the pairs of parameters were highly significantly correlated. From this table, groups of uncorrelated parameters were selected (Draper and Smith, 1966). Four such groups were chosen. They are (1) RH-2, DWS-4 and LGL-1, (2) RH-2, MXW-1, DWS-4 and COS-1, (3) DWS-1, DWS-4 and COS-1, and (4) EVP-1, RH-2 and DWS-4. Table 55 lists the fitted regression equations and their associated mean square and percentage variation explained values for each of the seven genotypes. For most equations one to three of the three or four parameters entered were selected. For each multiple regression, a highly significant amount of the variation of the residuals could be explained by the given relations. Comparison of the four sets of variables showed that equations generated from the first set, including RH-2, DWS-4 and LGL-1, explained the greatest percentage of the variation for each of the seven cultivars. The percentages of variation explained by the use of multiple regression equations exhibited a slight improvement over those obtained previously with simple regression (tables 53 and 55) in most cases. The percentage of variation explained by the use of multiple regression analysis was not substantial; most values were less than 50%. It should also be noted that all multiple regression equations, except those concerning the residuals of 70M009002 displayed a highly significant lack of fit.

2. Barley

Analysis of the nature of the barley drying curves was

Table: 54 Simple Correlations Among Weather Parameters Used for Multiple Regression Analysis of the Wheat Drying Curve Residuals (n=18)

Parameter	PPT-1	PPT-2	EVP-1	RH-2	MXW-1	DWS-1	DWS-4	COS-1	LGL-1
PPT-2	0.662 **[1]								
EVP-1	-0.816 **	-0.532 *							
RH-2	0.488 *	0.465 *	-0.394						
MXW-1	-0.511 *	-0.711 **	0.499 *	-0.238					
DWS-1	0.725 **	0.792 **	-0.501 *	0.476 *	-0.679 **				
DWS-4	-0.123	-0.094	0.202	-0.322	0.122	-0.192			
COS-1	-0.480 *	-0.191	0.522 *	-0.172	0.433	-0.437	0.313		
LGL-1	-0.621 **	-0.493 *	0.591 **	-0.040	0.787 **	-0.606 **	0.266	0.665 **	
BRS-1	-0.684 **	-0.514 *	0.698 **	-0.127	0.778 **	-0.584 **	0.139	0.719 **	0.948 **

1 *,** indicate siginificance at the 5% and 1% levels of significance respectively

Table: 55 Summary of Multiple Regression Analyses of Drying Curve Residuals for Seven Wheat Genotypes

Genotype	Regression Equation	Mean Square Regression	Mean Square LOF[1]	Variation Explained (%)
Park	$Y = 1.70 + 0.18\ RH\text{-}2 - 0.001\ LGL\text{-}1$	775 **[2]	63 **	48.4
	$Y = 18.63 - 0.70\ MXW\text{-}1 - 0.07\ DWS\text{-}4$	688 **	70 **	44.7
	$Y = -1.46 + 0.09\ DWS\text{-}1 - 0.06\ DWS\text{-}4$	584 **	84 **	37.9
	$Y = 12.84 - 9.42\ EVP\text{-}1 - 0.06\ DWS\text{-}4$	692 **	70 **	44.9
Neepawa	$Y = 3.99 + 0.20\ RH\text{-}2 - 0.07\ DWS\text{-}4 - 0.001\ LGL\text{-}1$	846 **	143 **	46.2
	$Y = -3.74 + 0.16\ RH\text{-}2 - 0.08\ DWS\text{-}4 - 6.67\ COS\text{-}1$	745 **	165 **	40.7
	$Y = 9.75 - 0.09\ DWS\text{-}4 - 6.95\ COS\text{-}1$	1018 **	167 **	37.1
	$Y = 13.86 - 7.23\ EVP\text{-}1 - 0.11\ DWS\text{-}4$	864 **	185 **	32.2
Norquay	$Y = 5.09 + 0.20\ RH\text{-}2 - 0.08\ DWS\text{-}4 - 0.001\ LGL\text{-}1$	897 **	114 **	51.3
	$Y = 18.43 - 0.46\ MXW\text{-}1 - 0.10\ DWS\text{-}4 - 5.08\ COS\text{-}1$	829 **	129 **	47.4
	$Y = 6.02 - 0.05\ DWS\text{-}1 - 0.09\ DWS\text{-}4 - 5.63\ COS\text{-}1$	786 **	138 **	45.0
	$Y = 15.24 - 8.47\ EVP\text{-}1 - 0.11\ DWS\text{-}4$	1037 **	148 **	39.5
Glenlea	$Y = -5.95 + 0.27\ RH\text{-}2 - 0.001\ LGL\text{-}1$	915 **	144 **	36.9
	$Y = -13.85 + 0.23\ RH\text{-}2 - 7.20\ COS\text{-}1$	805 **	159 **	32.4
	$Y = 4.49 - 8.08\ COS\text{-}1$	1160 **	177 **	23.4
	$Y = 12.29 - 8.98\ EVP\text{-}1 - 0.06\ DWS\text{-}4$	634 **	181 **	25.6
Pitic 62	$Y = -2.76 + 0.29\ RH\text{-}2 - 0.06\ DWS\text{-}4 - 0.001\ LGL\text{-}1$	984 **	159 **	41.8
	$Y = -9.69 + 0.24\ RH\text{-}2 - 0.06\ DWS\text{-}4 - 8.61\ COS\text{-}1$	1022 **	151 **	43.5
	$Y = 10.47 - 0.08\ DWS\text{-}4 - 9.02\ COS\text{-}1$	1314 **	170 **	37.3
	$Y = 16.06 - 9.67\ EVP\text{-}1 - 0.10\ DWS\text{-}4$	1115 **	197 **	31.6
70M009002	$Y = -3.74 + 0.25\ RH\text{-}2 - 0.001\ LGL\text{-}1$	920 **	59	37.1
	$Y = -3.31 + 0.19\ RH\text{-}2 - 0.39\ MXW\text{-}1 - 5.28\ COS\text{-}1$	549 **	77	33.2
	$Y = 4.26 - 7.67\ COS\text{-}1$	1046 **	105 **	21.1
	$Y = 13.73 - 10.51\ EVP\text{-}1 - 0.06\ DWS\text{-}4$	797 **	75	32.1
70M110001	$Y = -0.69 + 0.22\ RH\text{-}2 - 0.001\ LGL\text{-}1$	899 **	85 **	43.0
	$Y = -9.40 + 0.18\ RH\text{-}2 - 7.69\ COS\text{-}1$	753 **	105 **	36.0
	$Y = 7.71 - 0.06\ DWS\text{-}4 - 7.11\ COS\text{-}1$	749 **	105 **	35.8
	$Y = 13.59 - 9.43\ EVP\text{-}1 - 0.07\ DWS\text{-}4$	775 **	102 **	37.0

1 Mean Squares due to Lack of Fit

2 ** indicates significance at the 1% level of significance

separated into two parts. The first section was concerned with fitting curves to the data. The second part dealt with the influence of various weather parameters upon fluctuations about the drying curves. Three types of regression models were fitted to data of all six cultivars in three replicates for an overall regression analysis (table 56). The three models employed were the simple regression, polynomial regression and multiple regression models. Two types of transformations of the data were tested in an attempt to improve the fit of the data to the models. Percent moisture content values expressed on a dry weight basis was one transformation, and converted to reciprocal values was the second transformation utilized.

The simple regression model provided only a poor fit of the data in each of the four cases tested (table 56). Also the amount of variation explained in each case was considerably less than that found in the wheat experiment (table 51). The reciprocal transformation was not able to improve the linearity of the data as evidenced by the values of percent variation explained. Better fits of the data were obtained using either the polynomial or the multiple regression models in the analysis. For the reciprocally transformed values the use of the multiple regression model enhanced the fit of the data only slightly over that found for the simple regression analysis. The reciprocally transformed data sets demonstrated the poorest fits of the alternatives tested. The percent variation explained by the polynomial and multiple regression models was very similar. For %mcdb values, the multiple regression model was able to explain a slightly greater percentage of the variation than the polynomial model. For the %mcwb data set, the reverse was true. Of the ten combinations of three models and two types of transformations,

the application of the multiple regression model to the %mcdb data set exhibited the best fit in terms of percent variation explained.

Using this model and %mcdb data sets, the analysis of each of the six barley cutivars was conducted. Table 57 lists the regression coefficients and values describing each analysis. For each genotype, a significant variance due to regression was found. The percent variation explained values were fairly high, although somewhat lower than those found in wheat. The value for Jubilee, 78.7% variation explained, was the lowest percentage recorded. A significant lack of fit was encountered for each regression analysis (figures 13, 14, 15, 16, 17, 18).

Multiple regression analysis of each cultivar in each replicate was run and analysis of variance conducted on the resultant regression coefficients. Differences in manner of drying among the six genotypes were tested using Duncan's Multiple Range test to compare regression coefficients (table 57). Differences among the cultivar means were significant at the 5% and 1% levels of significance for the b_0 and b_2 regression coefficients respectively. No significant differences could be detected among the cultivar means for the b_1 and b_3 coefficients. According the the b_0 values, the cultivars can be grouped into three overlapping classes. Olli and Gateway 63 had the lowest, and Galt the highest b_0 values. Ordering of the cultivars by b_2 values produced three distinct groups. Olli, the earliest genotype, gave the highest b_2 value, a value not significantly different from zero. The cultivars Gateway 63, Conquest and Bonanza produced slopes of the second line, as characterized by b_2, of intermediate value. The latest genotypes, Galt and Jubilee, gave rise to the largest slopes of the second line. In both cases, these slopes were highly significantly different from zero.

Table: 56 Summary of Results of Regression Analyses of Barley Drying Curves (based on the complete data set)

Type of Regression	Model	Variables	Equation	Mean Square Regression	Mean Square LOF [1]	Variation Explained (%)
Simple	$Y=b_0+b_1X+e$	Y=%mcwb X=days from seeding	Y= 110.80 -0.79 X	36554 **[2]	1400 **	59.7
		Y=%mcdb X=days from seeding	Y= 251.26 -1.95 X	224056 **	8612 **	59.0
		Y=reciprocal %mcwb X=days from seeding	Y= -5.59 +0.10 X	544 **	27 **	51.6
		Y=reciprocal %mcdb X=days from seeding	Y= -6.59 +0.10 X	544 **	27 **	51.6
Polynomial	$Y=b_0+b_1X+b_2X^2+b_3X^3+e$	Y=%mcwb X=days from seeding	$Y= 610.68 -12.29 X +0.08 X^2$	15407 **		75.4
		Y=%mcdb X=days from seeding	$Y= 1863.06 -40.32 X +0.29 X^2 -0.001 X^3$	99773 **		78.8
Multiple	$Y=b_0+b_1X_1+b_2X_2+b_3X_3+e$	Y=%mcwb X_1,X_2,X_3=dummy variables	$Y= 67.97 -6.66 X_1 -1.24 X_2 +0.71 X_3$	15291 **	898 **	74.9
		Y=%mcdb X_1,X_2,X_3=dummy variables	$Y= 151.92 -17.93 X_1 -2.37 X_2 -0.14 X_3$	100196 **	4050 **	79.1
		Y=reciprocal %mcwb X_1,X_2,X_3=dummy variables	$Y= 0.31 +0.66 X_1 +0.22 X_2 -0.23 X_3$	203 **	26 **	57.9
		Y=reciprocal %mcdb X_1,X_2,X_3=dummy variables	$Y= -0.69 +0.66 X_1 +0.22 X_2 -0.23 X_3$	203 **	26 **	57.9

1 Mean Squares due to Lack of Fit

2 ** indicates significance at the 1% level of significance

Table: 57 Summary of the Results of Multiple Regression Analysis of the Drying Curves of Six Barley Genotypes

Genotype	Regression Coefficients				Mean Square Regression	Mean Square LOF[1]	Variation Explained (%)
	b_0	b_1	b_2	b_3			
Olli	140.9 c[2]	-18.69 **[3] a	-0.42 ns a	0.58 ns a	13134 **	250 **	83.4
Gateway 63	141.3 c	-17.03 ** a	-1.75 * b	0.04 ns a	13790 **	506 **	85.1
Conquest	154.8 abc	-18.38 ** a	-2.07 * b	-1.42 ns a	17182 **	730 **	83.6
Bonanza	148.1 bc	-17.46 ** a	-2.05 * b	-1.05 ns a	15582 **	828 **	80.5
Galt	166.6 a	-18.69 ** a	-3.59 ** c	-1.18 ns a	22102 **	1135 **	80.1
Jubilee	159.8 ab	-17.31 ** a	-4.35 ** c	2.16 ns a	20554 **	1246 **	78.7

1 Mean Squares due to Lack of Fit

2 Means followed by the same letter do not differ significantly at the 5% level of siginificance by Duncan's Multiple Range test

3 *,** indicate significance at the 5% and 1% levels of significance respectively

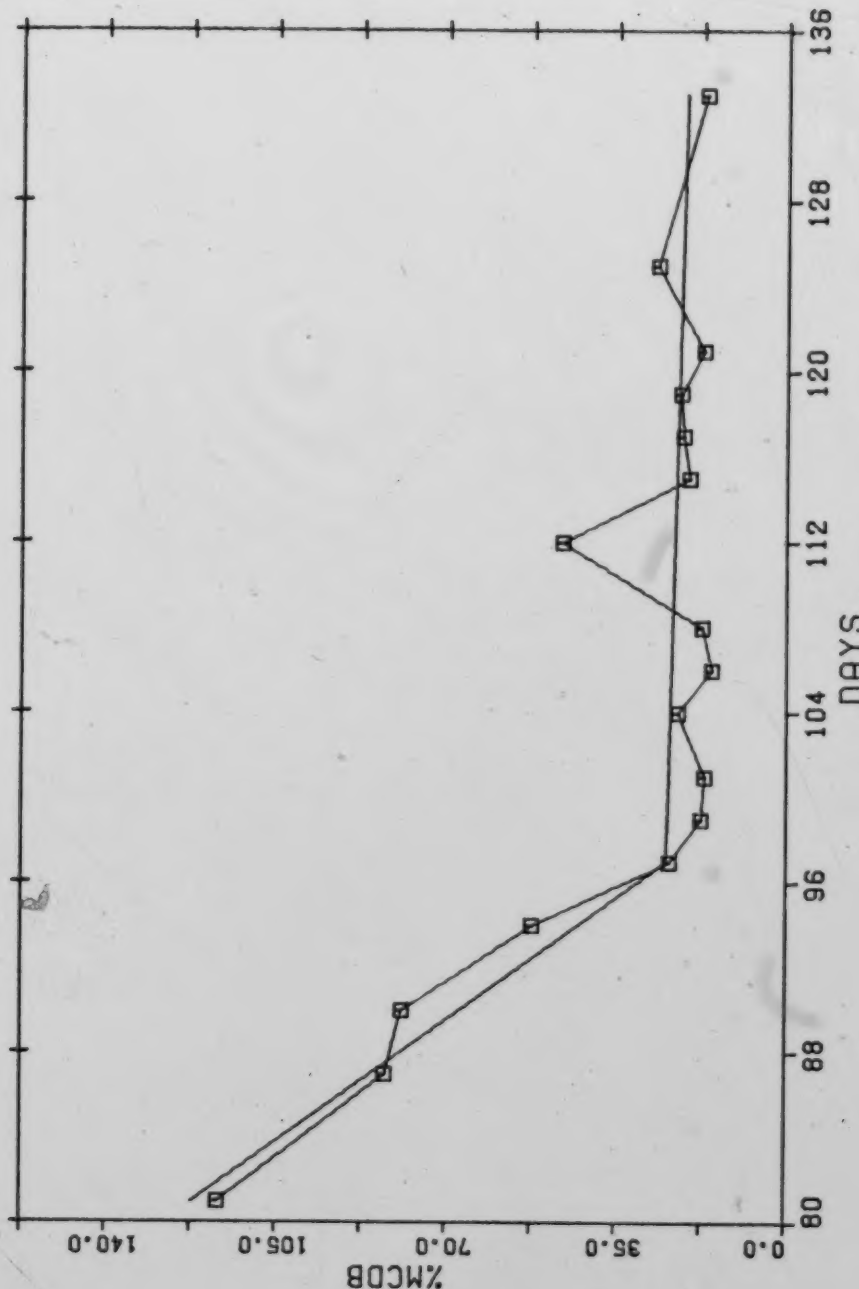

Figure: 13 Drying Curve and Fitted Multiple Regression Curve for Olli. %mcdb represents moisture content-dry basis, and days represents days from seeding.

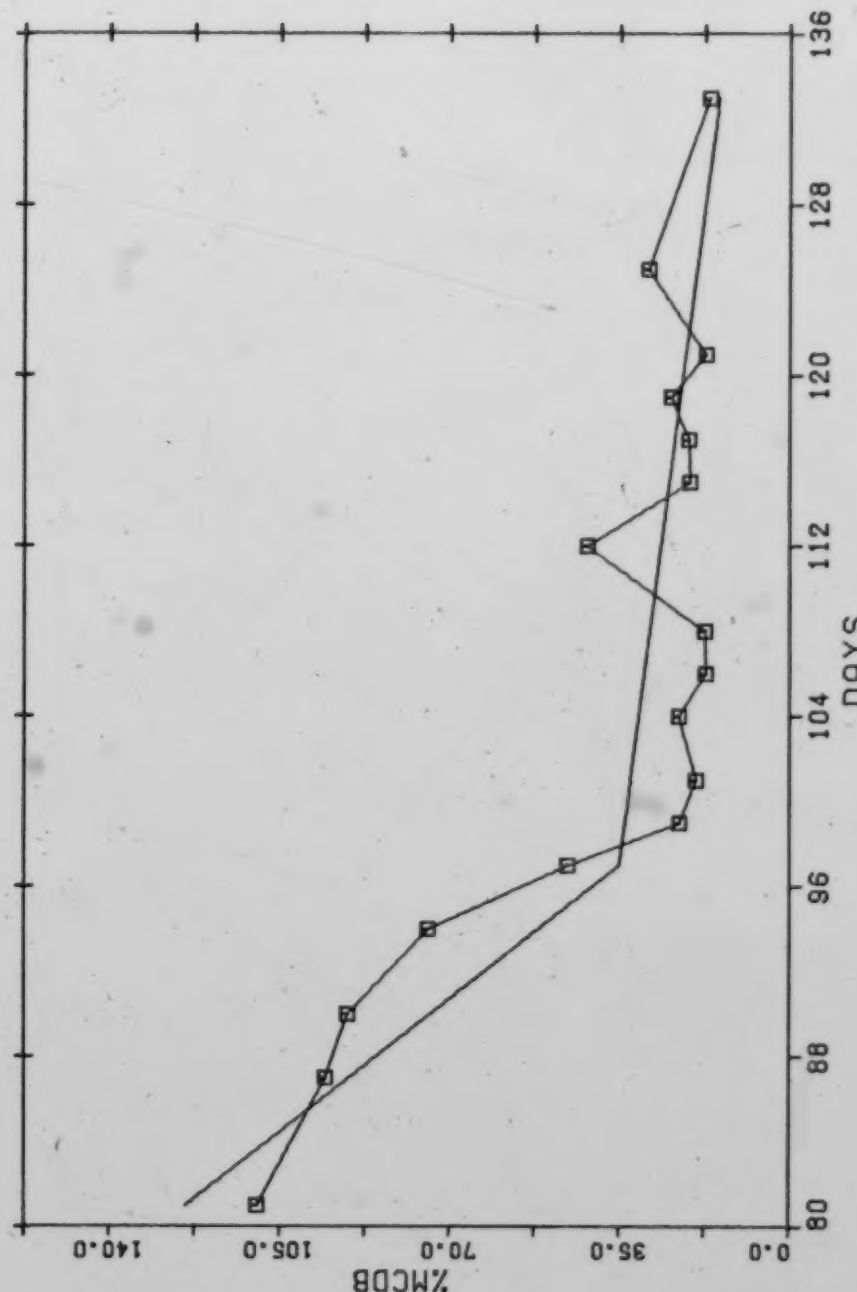

Figure: 14 Drying Curve and Fitted Multiple Regression Curve for Gateway 63. %mcdb represents moisture content-dry basis, and days represents days from seeding.

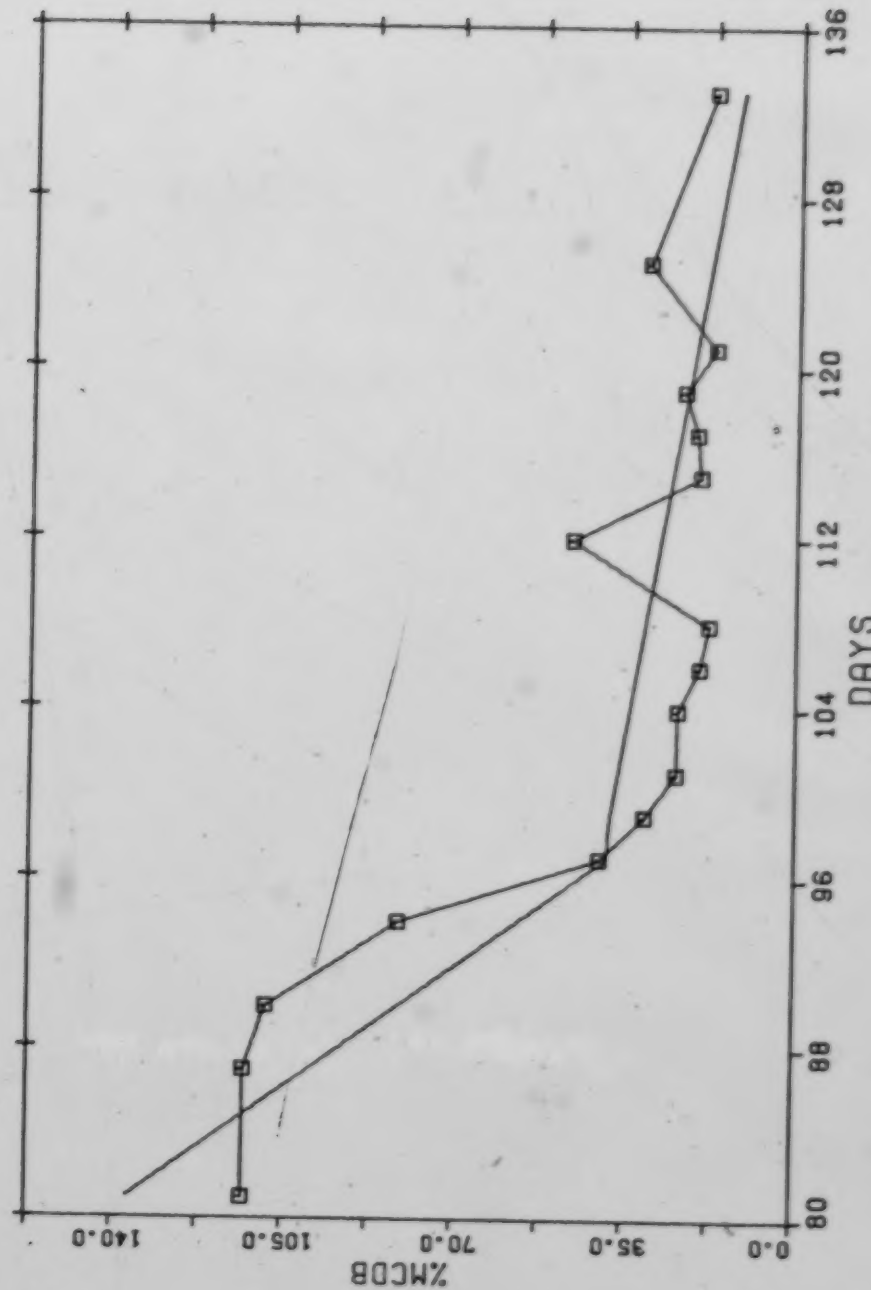

Figure: 15 Drying Curve and Fitted Multiple Regression Curve for Conquest. %mcdb represents moisture content-dry basis, and days represents days from seeding.

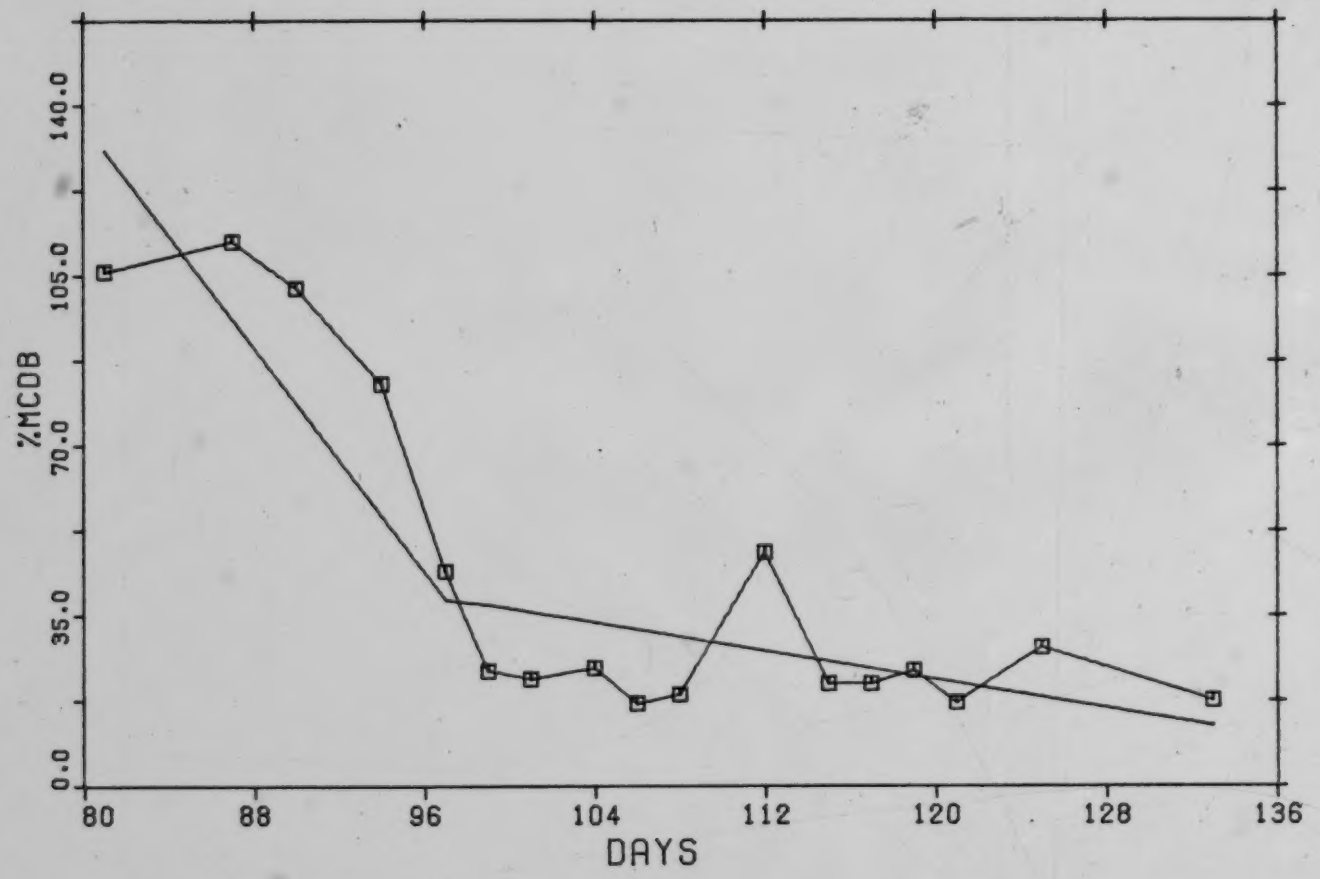

Figure: 16 Drying Curve and Fitted Multiple Regression Curve for Bonanza. %mcdb represents moisture content-dry basis, and days represents days from seeding.

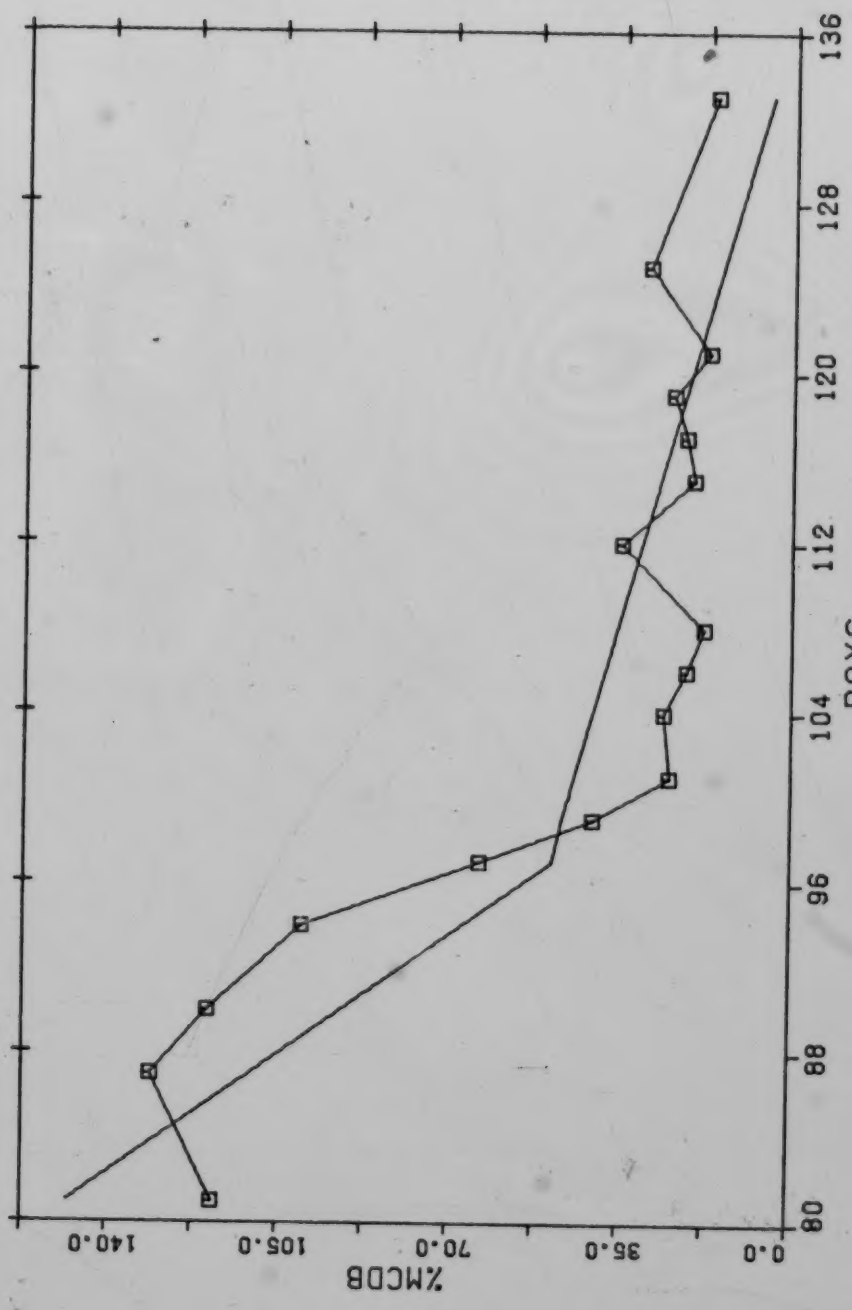

Figure: 17 Drying Curve and Fitted Multiple Regression Curve for Galt. %mcdb represents moisture content-dry basis, and days represents days from seeding.

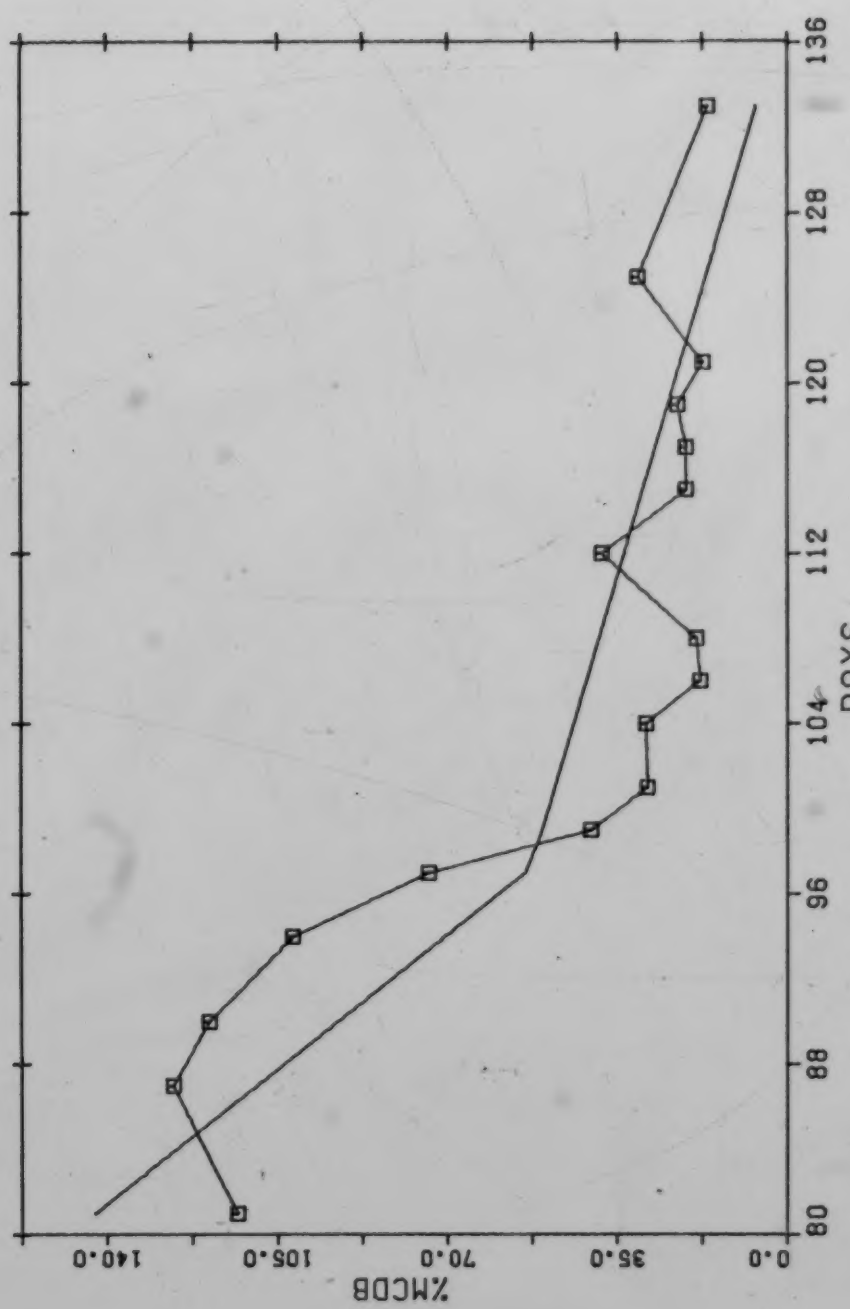

Figure: 18 Drying Curve and Fitted Multiple Regression Curve for Jubilee. %mcdb represents moisture content-dry basis, and days represents days from seeding.

The initial step of quantifying the influence of the weather upon drying was to choose a subset of variables with which to work. Simple correlations between the residuals generated from the fitting of the %mcdb values with the multiple regression model and several weather parameters were calculated (table 58). Many of the weather parameters exhibited significant correlation with the residuals (54 of 90). Of these parameters ten demonstrating the highest correlation values were selected. The chosen weather parameters were:

1. evaporation at -1 days (in) EVP-1
2. relative humidity at -1 days (%) RH-1
3. bright sunshine at -5 days (h) BRS-5
4. solar radiation at -2 days (lgl) LGL-2
5. solar radiation at -5 days (lgl) LGL-5
6. bright sunshine at -2 days (h) BRS-2
7. relative humidity at -2 days (%) RH-2
8. precipitation at -1 days (mm) PPT-1
9. solar radiation at -3 days (lgl) LGL-3
10. daily wind run at -0 days (miles) DWS-0

Simple regression analysis was utilized to relate changes in each of these ten weather parameters to fluctuations in the residuals of each of the six cultivars tested in this experiment. Table 59 lists the regression coefficients for the three best fitting regressions for each cultivar. Evaporation was able to explain relatively high proportion of the variation in the residuals for four of the six cultivars. For Galt and Jubilee, the late genotypes, the measure of solar radiation, hours of bright sunshine five days prior to sampling was

Table: 58 Simple Correlations Between Several Weather Parameters and Barley Drying Curve Residuals (n=306)

Weather Parameter	Days from Sampling					
	0	-1	-2	-3	-4	-5
DGD	0.169 **[1]	-0.086	0.079	0.041	0.003	-0.080
MXT	0.152 **	-0.183 **	-0.229 **	0.021	-0.131 *	-0.222 **
MNT	0.161 **	0.050	0.359 **	0.066	0.193 **	0.121
GRS	0.190 **	0.124 *	0.378 **	0.103	0.093	0.187 **
DEW	0.305 **	0.206 **	0.363 **	0.182 **	0.313 **	0.015
RH	0.084	0.579 **	0.494 **	0.203 **	0.294 **	0.212 **
PPT	-0.306 **	0.452 **	0.307 **	-0.043	-0.062	0.195 **
DWS	-0.380 **	-0.047	-0.031	-0.095	-0.141 *	-0.133 *
WSA	-0.0	0.014	0.015	0.016	0.019	0.025
MXW	0.205 **	-0.152 **	-0.248 **	-0.031	-0.042	-0.297 **
MNW	0.194 **	0.104	0.015	0.220 **	0.012	0.059
EVP	0.176 **	-0.590 **	-0.096	-0.245 **	0.152 **	-0.223 **
COS	0.213 **	-0.323 **	-0.294 **	-0.196 **	0.128 *	-0.339 **
LGL	0.129 *	-0.174 **	-0.552 **	-0.426 **	-0.009	-0.523 **
BRS	0.336 **	-0.282 **	-0.521 **	0.244 **	0.014	-0.555 **

1 *,** indicate significance at the 5% and 1% levels of significance respectively

Table: 59 Summary of Simple Linear Regression Analysis of the Drying Curve Residuals for Six Barley Genotypes

Genotype	Weather Parameter	Regression Coefficient		Mean Square Regression	Mean Square LOF[1]	Variation Explained (%)
		b_0	b_1			
Olli	PPT-1	-3.59	2.96 **[2]	2571 **	26	54.2
	EVP-1	16.45	-16.96 **	2193 **	68 *	46.3
	LGL-2	14.29	-0.001 **	1318 **	129 **	27.8
Gateway 63	EVP-1	21.31	-21.97 **	3681 **	182 **	50.7
	RH-1	-43.02	0.58 **	3354 **	168 **	46.1
	BRS-5	13.42	-1.59 **	2781 **	254 **	38.3
Conquest	EVP-1	26.26	-27.08 **	5590 **	239 **	55.2
	LGL-2	28.10	-0.002 **	5099 **	293 **	50.3
	RH-1	-52.48	0.71 **	4991 **	293 **	49.3
Bonanza	EVP-1	27.13	-27.96 **	5964 **	301 **	52.5
	LGL-2	28.59	-0.003 **	5279 **	366 **	46.5
	RH-1	-53.46	0.73 **	5180 **	334 **	45.6
Galt	BRS-5	23.01	-2.73 **	8185 **	438 **	49.6
	LGL-5	40.43	-0.003 **	7308 **	496 **	44.3
	RH-1	-60.76	0.83 **	6690 **	492 **	40.6
Jubilee	BRS-5	23.69	-2.81 **	8671 **	502 **	52.1
	LGL-5	40.50	-0.003 **	7334 **	591 **	44.0
	RH-1	-59.99	0.82 **	6523 **	556 **	39.2

1 Mean Squares due to Lack of Fit

2 *, ** indicate significance at the 5% and 1% levels of significance respectively

most effective in explaining deviations in the residuals. This relationship may be spurious as it was not expected.

The mean square value for regression was significant in all cases, and highly significant in most cases. Value of percent variation explained were fairly high (table 59). The highest, 54.2%, came from the regression of Olli's residuals on the PPT-1 values. Thus although a substantial amount of the variation in the varietal residuals may be explained by regression upon weather parameters taken individually, there remained a considerable portion of the vaiance unexplained. Significant mean square values for lack of fit for most of the regressions confirmed this observation. The regression of Olli residuals on PPT-1 was the one exception, displaying a nonsignificant lack of fit.

In order to improve the fit of the residuals or reduce the unaxplained variation, multiple regression was used. The influence of several weather parameters acting in concert upon the residuals was tested. Four different subsets of uncorrelated weather variables were selected for the multiple regression analysis. These sets of variables included (1) EVP-1, RH-2, LGL-3 and LGL-5, (2) PPT-1, RH-2, LGL-3 and BRS-5, (3) DWS-0, PRT-1, LGL-3 and LGL-5, and (4) DWS-0, RH-1, LGL-3 and BRS-5. Table 60 lists the simple correlation values for all pairs of the ten weather parameters. Based upon these values the above sets of variables were selected.

Four multiple regression analyses for the residuals of each cultivar were conducted; each analysis employing a different subset of variables. The results of the analysis are presented in table 61. In all 24 cases, the mean square due to regression was highly

Table: 60 Simple Correlations Among Weather Parameters Used for Multiple Regression Analysis of the Barley Drying Curve Residuals (n=17)

Parameter	DWS-0	RH-1	RH-2	PPT-1	EVP-1	LGL-2	LGL-3	LGL-5	BRS-2
RH-1	-0.301								
RH-2	-0.595 *[1]	0.554 *							
PPT-1	-0.182	0.549 *	0.439						
EVP-1	0.238	-0.602 *	-0.417	-0.864 **					
LGL-1	0.541 *	-0.492 *	-0.545 *	-0.486 *	0.558 *				
LGL-3	0.452	-0.112	-0.311	0.014	0.072	0.573 *			
LGL-5	0.462	-0.513 *	-0.370	-0.190	0.358	0.337	0.127		
BRS-2	0.604 *	-0.457	-0.665 **	-0.514 *	0.549 *	0.950 **	0.564 *	0.223	
BRS-5	0.427	-0.440	-0.349	-0.146	0.418	0.358	0.198	0.916 **	0.259

1 *,** indicate siginificance at the 5% and 1% levels of significance respectively

Table: 61 Summary of Multiple Regression Analyses of the Drying Curve Residuals of Six Barley Genotypes

Genotype	Regression Equation	Mean Square Regression	Mean Square LOF[1]	Variation Explained (%)
Olli	$\hat{Y}$= 25.71 -16.58 *EVP-1* -0.001 *LGL-3*	1201 **[2]	60	50.7
	$\hat{Y}$= 8.67 +2.98 *PPT-1* -0.001 *LGL-3*	1457 **	24	61.5
	$\hat{Y}$= 8.67 +2.98 *PPT-1* -0.001 *LGL-3*	1457 **	24	61.5
	$\hat{Y}$=-26.94 +0.37 *RH-1*	1315 **	129 **	27.8
Gateway 63	$\hat{Y}$= 51.90 -17.72 *EVP-1* -0.002 *LGL-3* -0.001 *LGL-5*	1861 **	77 **	76.8
	$\hat{Y}$= 29.13 +2.54 *PPT-1* -0.002 *LGL-3* -1.20 *BRS-5*	1857 **	78 **	76.6
	$\hat{Y}$= 37.92 +2.49 *PPT-1* -0.002 *LGL-3* -0.001 *LGL-5*	1749 **	103 **	72.2
	$\hat{Y}$= -4.03 +0.43 *RH-1* -0.002 *LGL-3* -0.85 *BRS-5*	1718 **	110 **	70.9
Conquest	$\hat{Y}$= 43.46 -19.64 *EVP-1* +0.19 *RH-2* -0.002 *LGL-3* -0.001 *LGL-5*	2176 **	66 **	85.9
	$\hat{Y}$= 34.64 +3.19 *PPT-1* -0.002 *LGL-3* -1.41 *BRS-5*	2734 **	100 **	81.0
	$\hat{Y}$= 46.72 +3.09 *PPT-1* -0.002 *LGL-3* -0.002 *LGL-5*	2707 **	106 **	80.2
	$\hat{Y}$= -6.53 +0.53 *RH-1* -0.002 *LGL-3* -0.98 *BRS-5*	2497 **	154 **	74.0
Bonanza	$\hat{Y}$= 46.65 -19.82 *EVP-1* +0.21 *RH-2* -0.002 *LGL-3* -0.001 *LGL-5*	2475 **	72 **	87.2
	$\hat{Y}$= 39.41 +3.32 *PPT-1* -0.002 *LGL-3* -1.49 *BRS-5*	3169 **	97 **	83.8
	$\hat{Y}$= 52.03 +3.22 *PPT-1* -0.003 *LGL-3* -0.002 *BRS-5*	3125 **	107 **	82.6
	$\hat{Y}$= -0.75 +0.52 *RH-1* -0.002 *LGL-3* -1.08 *BRS-5*	2824 **	177 **	74.7
Galt	$\hat{Y}$= 80.14 -16.69 *EVP-1* -0.003 *LGL-3* -0.002 *LGL-5*	3978 **	217 **	72.4
	$\hat{Y}$= 49.24 +1.89 *PPT-1* -0.003 *LGL-3* -2.30 *BRS-5*	3778 **	263 **	68.7
	$\hat{Y}$= 68.40 +1.74 *PPT-1* -0.003 *LGL-3* -0.003 *LGL-5*	3644 **	294 **	66.3
	$\hat{Y}$= 7.73 +0.51 *RH-1* -0.002 *LGL-3* -1.78 *BRS-5*	4126 **	183 **	75.1
Jubilee	$\hat{Y}$= 83.91 -17.92 *EVP-1* -0.003 *LGL-3* -0.002 *LGL-5*	4271 **	260 **	76.9
	$\hat{Y}$= 52.67 +2.03 *PPT-1* -0.003 *LGL-3* -2.34 *BRS-5*	4143 **	290 **	74.6
	$\hat{Y}$= 71.24 +1.90 *PPT-1* -0.003 *LGL-3* -0.003 *LGL-5*	3897 **	346 **	70.2
	$\hat{Y}$= 13.85 +0.48 *RH-1* -0.003 *LGL-3* -1.87 *BRS-5*	4365 **	239 **	78.6

1 Mean Squares due to Lack of Fit

2 ** indicates significance at the 1% level of significance

significant. The percent variation explained values were greater than 50% in all but one analysis; that case being the regression of Olli residuals on data set 4. Generally a substantially greater proportion of the variation in the barley residuals was explained by fluctuations in weather parameters than was possible for the wheat residuals.

Significant lack of fit was found for most analyses. Nonsignificant lack of fit was found for three of four regression analyses involving Olli residuals.

DISCUSSION

I. Harvesting Methodology

Accurate, reliable assessments of experimental lines are essential to any productive breeding program. Selection of new material must be based upon characters defining true agronomic and market worth. Currently employed methods of testing and licensing new cultivars appear to be satisfactory in this respect (Briggs, 1976). It is known that harvesting practices may influence both yield (Dodds, 1967; Koenig et al., 1965) and quality (Koenig et al., 1965; Dodds, 1967; Spillane, 1973), therefore, any change in current harvesting methods must be introduced with caution.

A. Wheat

The effects of ten harvesting treatments were monitored with the performance of seven well-characterized genotypes. The characters studied, with the exception of tillering and dockage are commonly assessed in both Utility and Hard Red Spring wheat breeding programs. Evaluation and selection of lines for advancement within breeding programs are based upon these characters and characters not subject to the influence of harvesting operations such as maturity and disease resistance. The characters tillering and dockage were included in the study in an attempt to partially characterize differences among the various harvesting treatments. The influence of harvesting operations on bread-making quality was not assessed in this study. It

would be useful for hard red spring wheat breeders to conduct a similar harvesting methodology study in which bread-making quality parameters were monitored, as the results in the literature are contradictory (Scott et al., 1957; Spillane, 1973).

The genotypes were selected for this study as representative of some of the widely divergent types found in breeding programs in Western Canada. The results from the experiment confirmed this assessment of the seven genotypes. Highly significant differences among genotypic means were found for all characters measured except yield (tables 6, 7 and 8). It is difficult to explain the lack of significant differences among the genotypes for yield as past research suggests that such differences exist (Alberta Cereal and Oilseed Advisory Committee, 1977; Attinaw, 1977).

Harvesting treatments had a significant influence upon all of the characters measured, including yield (tables 6 , 7 and 13). No one of the nine alternate harvesting treatments produced the same mean value as the control or conventional harvest system for all of the characters studied (table 13).

The earliest harvest treatment, swath and thresh one week prior to physiological maturity of the earliest genotype (treatment 2), displayed depressed values for several characters, including protein content, germinative ability, seed weight and test weight. The yield mean of treatment 2 was high and likely inflated by high wet weights, from harvesting immature grain. Treatment 2 produced the lowest yield values of the ten harvesting treatments when the yield values were expressed on a dry weight basis (table 14). Several other researchers have reported similar results (Dodds, 1967; Spillane, 1973).

The latest harvest treatment, treatment 10, gave rise both to very low test weights and low yields. Shattering of plump, overripe kernels may have caused both of these results. Also kernel damage from threshing very dry, brittle kernels may have also depressed test weights (Dodds, 1974; Yamazaki and Briggle, 1969).

Treatments 8 and 9 were straight combining treatments differing only in the type of plot used. Plots used for treatment 9 were bordered by blank guard rows. It has been suggested that the separation of plots, either with blank rows or nonheading winter wheat may facilitate the identification and harvesting of plots with a combine (Briggs, 1976). Therefore, treatment 9 was included in this experiment to test the effects of plot type on harvesting operations and on assessments of gentoypes. For most characters, with the exception of protein content and yield, treatments 8 and 9 were indistinguishable by Duncan's Multiple range test (table 13). The average protein content for treatment 9 was significantly higher than that of harvest treatment 8, and the average yield of treatment 9 was greater than that of 8. Both of these results may be attributed to the increased tillering of all cultivars with the treatment 9 plot type. The kernels from secondary tillers are often less plump and more immature than main tillers, and therefore, they are more likely to have higher protein contents. Thus plot type was found to have a significant influence on two of the more important characters to a Utility wheat breeding program.

For some characters, the three straight combining treatments gave results that were very similar, and different from the remaining harvest treatments. This was true of germination and dockage. The similarity of germination values may reflect differences in harvesting

with the Hege combine, or they may reflect the time of harvest. The dockage values suggest the cleaning mechanisms of the Hege were more thorough than those of the Vogel thresher. For the character yield, there is some suggestion that the straight combining harvest operations produce smaller yields. The yield of treatment 9 may be inflated by extra tillering of the genotypes as suggested above. Thus for two, and possibly three characters, the "swath and thresh" harvests did not provide an accurate simulation of the straight combining regime. It is difficult however, to separate the straight combining effects of treatments 8, 9 and 10 from the timing of the harvests. All three harvests were conducted late in the growing season. The reduced moisture content of the standing crop at harvest (table 4) could have facilitated threshing, and reduced dockage values; and it would have reduced the possibility of storage fungi infecting the harvested grain samples, thus improving germination values. Yield values for late harvests were likely depressed by shattering.

That harvest treatments modified the mean values of all of the characters studied, emphasizes the dependence of such assessments upon techniques used in determining these parameters. It also emphasizes the need for standardization of harvesting practices if assessments of lines from tests conducted in different years and locations are to be compared.

The occurrence of significant genotype x harvest treatment interaction effects for most of the characters studied has important implications for breeding programs. Harvesting operations can affect not only the mean values for several characters, but also the relative performances of lines within a test. Thus the use of alternate harvesting techniques can produce alternate assessments of the relative worth

of lines in a test.

The relationship between the evaluation of the seven wheat genotypes based upon the results from treatment 1, the control treatment, and from the nine alternate harvesting methods was examined in two ways. Groupings or relative rankings of the genotypes of the nine alternate harvesting treatments were compared with the results of the control harvest regime. It was reasoned that only those changes of rank producing significantly different groupings of the genotypes would be of consequence to the assessment and selection of superior lines. This reasoning can only be accepted with reservation as it is a fairly common practice in breeding programs to select as many of the best lines as can be grown the following season (Briggs, 1976). The specified number of lines are not selected at random from the best groups of lines but rather the top ranking lines within the best groups are selected for advancement. Thus although, switching of rank within a group of lines indistinguishable by Duncan's Multiple Range test or some similar test, will not influence evaluations of lines, it may influence the selection of lines for advancement. From this point of view, any alteration of the rank of genotypes within a test can be considered important. The second measure of similarity between the alternate harvesting treatments and the conventional system was the simple correlation. It provides a measure of the common variation of the genotypic means between two harvest treatments.

Tables 18, 19, 20, 21, 22 and 23 present the genotype x harvest treatment interaction means for this experiment. For five of the six characters, none of the nine alternate harvesting operations were able to reproduce the grouping of the seven genotypes displayed for

treatment 1. The one exception was the character yield, which will be discussed below. For the characters, protein content, seed weight and test weight, the correlation values for all nine alternate methods were generally high and positive; whereas, for germination and dockage, they were commonly nonsignificant. Thus, for three characters, protein content, seed weight and test weight, some of the alternate harvesting methods studied may be considered as acceptable alternatives to the control method if the breeder is willing to accept some degree of misclassification of lines. However one harvest treatment satisfactory as a replacement to the conventional method for all characters was not found. If the status quo evaluations of genotypes are to be maintained then changes in harvesting pratices such as those studied in this test, cannot be recommended.

Yield was one of the more complex characters to analyze. Although no genotypic effects were found, yield values from this test were sensitive to harvest treatments, yield measures and several interaction effects. As one of the most important characters in the selection of new lines, it is of concern that yield is unstable. Therefore, higher order interactions were studied in order to determine which harvest treatment - yield measure treatment combination most faithfully reproduced the evaluation of the seven genotypes of the current method of harvest (harvest treatment 1, with dry, uncleaned, unadjusted weights).

Conclusions drawn from the genotype x harvest treatment interaction means for yield are different from those of the other five characters displaying significant genotype x harvest treatment terms. Eight of the nine alternate harvesting regimes produced a grouping of

the seven wheat genotypes identical to the control treatment (table 23). The exceptional treatment was treatment 9, straight combining in plots with blank guard rows. Thus, with the exception of treatment 9, any one of the alternate harvesting treatments could be used in place of the conventional system if only the character yield was of concern.

Of the significant genotype x yield measure interaction terms, only for the genotype x drying x moisture adjustment interaction did evaluations of the genotypes change (tables 9, 10, 11 and 12). Use of wet, unadjusted weights gave rise to an evaluation of the seven genotypes different from the remaining three yield measures of that interaction.

If genotype x harvest treatment x yield measure interaction means are considered, few of the possible treatment combinations produce a detectable alteration of assessments of the genotypes based upon Duncan's Multiple Range test (tables 24, 25, 26 and 27). Harvest treatment 9 and treatment 3 are commonly the anomalous treatments. However if for the genotype x harvest treatment x drying x moisture adjustment treatment combinations, the correlation values are examined, none of the remaining acceptable treatment combinations gave very high correlation values with the control treatment combination. The highest correlations, as would be expected, were produced by treatment 1 using wet, unadjusted; wet, adjusted or dry, adjusted weights. All three of these sets of values were derived from the control values. Of the remaining treatment combinations, harvest treatments 10 and 2 usually gave the highest correlations and treatment 9 the lowest correlation with the current harvesting method. Yield measure dry, unadjusted weights generally gave higher correlations with the control than the remaining yield measures.

Treatments 2 and 10 cannot be considered as practical alternatives the control harvesting regime because they are too early and too late respectively. Of the remaining treatment combinations, treatments 5, swath and thresh at the physiological maturity of Norquay and 70M009002, and 6, swath and thresh at the physiological maturity of Glenlea and Pitic 62, using either dry, unadjusted or dry, adjusted weights provided the highest correlations with the control (table 27).

There is some difficulty in drawing conclusions from the yield data because genotypic differences among the cultivars known to exist with respect to yield failed to manifest themselves in this experiment. Therefore the inability to detect differences among many of the harvest treatments, based upon grouping of the genotypes using Duncan's Multiple Range values, does not necessarily imply that such differences do not exist. For the character yield, the seven genotypes chosen for this study, proved unsuitable for evaluating the effects of alternate harvesting treatments. This result could not have been anticipated from previous descriptions of the genotypes (Alberta Cereal and Oilseed Advisory Committee, 1977; Attinaw, 1977).

Some consideration must also be given to influence of moisture adjustment on seed weights and test weights as both significant genotype x moisture adjustment and harvest treatment x moisture adjustment interactions were found (table 6). From tables 8 and 13, grouping of the wheat genotypes and harvest treatments was unchanged by moisture adjustment for all except harvest treatment test weight means. Thus, it would appear that for seed weight and test weight, moisture adjustment generally does not have a major effect upon assessments of genotypes and harvest treatments. This is to be expected as during drying and storage,

most samples should have attained fairly similar moisture contents, and further adjustment of weights to a constant moisture basis would be unnecessary. In the case of test weights, some authors have questioned the soundness of making adjustments for moisture such as was done in this test (Pushman, 1975). Alteration of test weight with changes in moisture content is not a straightforward, linear process, but involves changes in density, as well as changes in the proportion of dry matter. Thus there is some bias in the use of adjusted test weights which may negate the advantages of adjustment.

B. Barley

Conclusions similar to those drawn from the wheat experiment can be made from the results of the barley harvesting methodology test.

The characters assayed in the barley test were similar to those studied in the wheat harvesting study. These characters are commonly measured in barley yield trials and provide the basis for the selection of genotypes for advancement within the breeding program. Two additional germination parameters were included in the barley test. Germination resistance and uniformity factor are two terms coined by Gordon (1971) to describe or quantify the germination of the sample as to rapidity and uniformity. It is important to the malting industry that samples of barley have not only high germination but also rapid, uniform germination. Therefore, it is advantageous for a malting barley breeder to monitor these two additional parameters of germination. Several other properties are important to the malting and brewing quality of barley samples and although not assessed in this experiment, would be of interest to study in regard to harvesting practices.

The six genotypes studied in this test displayed a wide range of values for all of the characters measured, except yield and germination uniformity factor (table 31). As noted previously in the results section, genotypic means for the characters seed weight, test weight and yield contradicted to some extent those observed by other researchers (Alberta Cereal and Oilseed Advisory Committee, 1977; Hamid, 1977). Severe lodging and hot, dry weather during the harvest period may have affected kernel development, thereby, causing discrepancies between the results of this test and previous studies.

Hot, dry weather encountered during mid-August also had some influence upon harvest treatment effects. Difficulty was encountered in selecting correct harvest dates for the three harvest treatments (table 5). Only the earliest cultivars, Olli and Gateway 63 were harvested for harvest treatments 1 and 2 at moisture contents substantially higher than for the last treatment, treatment 3. Moisture contents of Bonanza, Galt and Jubilee for harvest treatment 3 were slightly higher than moisture contents reported for the earlier harvest because of moisture added by precipitation. Thus differences among the three harvest treatments attributable to differences in the state of kernel development were minimized. Differences among the three harvesting treatments were more likely caused by differential sensitivity to such factors as mechanical damage, lodging and shattering on the part of the cultivars.

Harvest treatments had a significant influence on four of the seven characters studied. For protein content, uniformity factor and seed weight no significant differences were detected among the harvest treatment means. The late swath and thresh harvest, treatment 3, produced values similar to the control harvest, treatment 1, for the

character germinative ability, in addition to protein content and seed weight.. Treatment 2 was indistinguishable from treatment 1 for the characters yield, protein content and seed weight. For the character test weight, the swath and thresh treatments were not significantly different. For the remaining character, germination resistance, each harvest treatment produced a significantly different mean value, with treatment 2 displaying the highest and the control method the lowest germination resistance means.

The lack of significant differences among the three harvest treatments for the characters protein content and seed weight supports earlier statements that kernel development was complete for all cultivars for all harvest treatments. The low germination and high germination resistance values observed for harvest treatment 2 are difficult to explain unless some additional maturation of the kernels is proposed for harvest treatments 1 and 3. The low yields displayed by treatment 3 are most likely due to shattering and lodging losses. The similarity of values observed for treatments 2 and 3 for the character test weight may relate to kernel damage from threshing undried grain samples.

From the discussion above, it is apparent that neither of the alternate swath and thresh harvest treatments produced mean values for all of the characters studied similar to the conventional system. As for wheat, this results suggests harvesting operations should be standardized if comparisons of lines are to be made over several tests.

For barley, only four of the seven characters studied proved sensitive to genotype x harvest treatment interaction effects. The three germination parameters, germinative ability, germination resistance and

uniformity factor, and test weight displayed significant genotype x harvest treatment terms, while protein content, seed weight and yield did not (tables 29 and 30). Thus relative assessments of barley genotypes may be influenced by harvesting operations for the former four characters. If a wider range of harvest treatments or even harvest dates had been studied the latter three characters may also have demonstrated significant genotype x harvest treatment terms such as was found in the more extensive wheat harvesting methodology experiment. In only one instance was the grouping of the six barley cultivars for the swath and thresh treatments identical to that of the control method. For the character germination resistance, treatment 3 mimicked the results of the conventional system (table 37). For another character, test weight, the late harvest treatment, treatment 3, gave a high positive correlation with the conventional harvesting procedure, and a similar, although not identical assessment of the genotypes. Thus for barley, as for wheat, the occurrence of significant genotype x harvest treatment interaction terms suggests that evaluation or relative assessments of lines within a test will change with harvesting practices. If the conventional system produces a satisfactory evaluation of true agronomic and market worth of new experimental lines, then any change of harvesting operations, such as those considered in this test, may produce a false assessment of lines and will deter advancement of superior lines in a breeding program. Therefore, from the results of the barley experiment, it must be recommended that the conventional harvest system be maintained.

For the character yield, the results in barley were similar to those from the wheat test. Although no genotypic effects were observed

in this study, yield values were influenced by harvest treatments, yield measures and some of the interaction effects. Unlike the wheat test, genotype x harvest treatment and harvest treatment x yield measure interaction terms were nonsignificant (table 30). Again the inability to detect significant interaction effects may be due to the narrow range of harvest treatments studied, or the small range of moisture contents of the cultivars between the two harvest dates. The highest order interaction term (genotype x harvest treatment x drying x moisture adjustment) was however found to be highly significant (table 42). Considering both criteria, the grouping of genotypes based upon Duncan's Multiple Range values and correlations, only treatment 1, using either wet, adjusted or dry, adjusted weights could be considered as acceptable alternatives to the control harvesting operations (harvest treatment 1, using dry, unadjusted weights). This relationship was expected as these two treatment combinations were derived from the control treatment combination. Neither of these treatment combinations provides a practical alternative to the conventional system of harvesting, as wet weights cannot be measured directly for treatment 1 in the first case, and adjusting dry weights to a constant moisture basis adds additional work to the harvesting operations. Any treatment combination involving harvest treatment 3 was unsatisfactory as a replacement for current harvesting practices as correlation values were very low or nonsignificant. Of the remaining treatment combinations, treatment 2 with either dry, unadjusted or dry, adjusted weights gave the highest correlations with the control. However adoption of either of these treatment combinations would likely introduce some misclassification of lines for the character yield. Thus it appears that none of the alternate

treatments studied are acceptable as replacements for the current labor intensive harvesting practices.

The effects of moisture adjustment on seed weight and test weight values were not major. No significant harvest treatment x moisture adjustment interaction effects were found for the barley test. Although genotype x moisture adjustment terms were significant for both characters, evaluations of the genotypes were identical for both unadjusted and adjusted weights. As with wheat, this result in barley, is to be expected as samples should have attained fairly similar moisture contents during drying and storage. Moisture adjustment of seed weight and test weight values can be considered unnecessary. Also as mentioned previously, adjustment of test weights to a constant moisture basis using the methods employed in this test may not be valid (Pushman, 1975).

II. Maturity Assessments

Incorporation of selection for maturity types into a cereal breeding program requires an acceptable method of assessing this character. For the short season growing areas of central and northern Alberta, early maturing types are required. The successful selection of early maturing lines is dependent upon the accuracy and reliability with which such measurements can be executed. Both the environment and the method of maturity determination can introduce variability or error into the assessment of experimental lines. Such error can obscure true differences among lines and impede advancement through selection.

A. Maturity Measures

Techniques able to detect small differences in maturity with a minimum of misclassification are essential to a productive breeding program. Currently utilized methods of determining maturity depend upon measures of moisture content or upon methods relating indirectly to the moisture content of the crop. The most accurate technique of determining maturity is probably the measurement of moisture content utilizing standard techniques developed by the A.A.C.C. (1962). This methods is very accurate, reproducible and is able to detect small differences in moisture content. However, standard forced-draft oven measures of maturity are impractical for field testing of a large number of experimental lines, such as is required for selection within a breeding program. A second measure of maturity commonly employed by cereal breeders is date of heading. The advantages offered by this method are that it is rapid, easy to score, and fairly reliable. Heading dates often exhibit strong positive correlations with final maturity (Briggs, 1976). However, because the two events are separated in time, it is possible that a certain proportion of genotypes will be misclassified if date of heading is the only measure of maturity used for the selection of early types. Such opportunities for error reduce the effectiveness of a selection program. Date of swathing ripeness is a third measure of maturity employed by some cereal breeders in the Prairies. This measure is primarily a visual rating of readiness for swathing (about 30%mcwb) based upon color of the plant and stage of kernel development (late dough stage). Date of swathing ripeness is a rapid method of assessing maturity. However, it suffers from the lack of reliability and accuracy inherent in any subjective measurement. In addition, the

timing of this third method of assessing maturity concurs with the harvesting operations and sufficient time to assess the lines properly is often not available. The fourth measure of maturity, a method adopted by the University of Alberta cereal breeding program, is a visual field rating of relative maturity, based upon a 1 - 9 score, before harvesting operations begin. Visual assessment of maturity offers advantages over each of the previous methods. It is a rapid, facile method. Assessments are made late in the growing season, minimizing the possibility of misclassification, and yet do not coincide with harvesting operations. The major disadvantage of field ratings of relative maturity is that they are subjective assessments, and therefore lack the accuracy necessary to detect small differences in maturity.

For the purposes of this study a fifth method of determining maturity was introduced on a trial basis. The moisture content of a sample of kernels was measured using a dielectric moisture meter, the Delmhorst G-6c. Because this apparatus is small and easy to use, large scale field testing of experimental lines is possible. Utilization of a moisture meter provides an objective measure of maturity that should be reasonably accurate and reliable.

It is out of concern for our ability to detect early maturing geotypes that this section of the study arose. The major concern was to compare the above five methods for accuracy, reliability, ability to detect small differences in maturity, applicability to immature material and usefulness for large scale field testing.

1. Wheat

For both the wheat and barley test, the measure days to 35%mcwb calculated from drying curves based upon standard moisture

content determinations, was used as the standard or reference method. This method of assessment was chosen as a standard because it satisfies four of the five requirements. Days to 35%mcwb does not satisfy the criterion of applicability to large scale field testing. The four remaining methods of maturity measurement were assessed on the basis of comparison to the control technique.

The seven genotypes studied displayed a wide range of maturities. For each of the five measures of maturity highly significant differences were found among the genotypes (table 44). However, none of the alternate techniques gave rise to the same classification of the genotypes, based upon Duncan's Multiple Range test, as the control method, days from seeding to 35%mcwb (table 45), emphasizing the difficulty of reliably and accurately detecting small differences in maturity among lines. From table 46, the measures days from seeding to swathing ripeness and days from seeding to heading provided the highest correlations with the control method. As mentioned above there are disadvantages to both of these methods of assessing maturity. The remaining two methods, developed to overcome some of the objections of days to swathing ripeness and days to heading, however, provided poorer correlations with the control method and thus increased possibilities for the misclassification of genotypes.

Two tests of the utility of the Delmhorst G-6c moisture meter were made. The Delmhorst G-6c was tested for accuracy using simple correlation and a t-test to compare Delmhorst G-6c values to standard air-oven determinations of moisture content for several samples of grain. A very high correlation value was found (r_{xy}=0.936, n=174) suggesting that the Delmhorst G-6c gave reliable estimates of moisture

content, However, Delmhorst values were not very accurate, as indicated by the t-test results (t=4.45, n=174). It is not surprizing that the mean of the standard air-oven determinations was significantly higher than that of the Delmhorst G-6c readings as the moisture meter was designed for measurement of samples less than 30%mcwb only. The relatively poor correlation between Delmhorst G-6c readings and days from seeding to 35%mcwb is likely a reflection of the inadequacy of the moisture meter with grain of high moisture content. Thus, although the use of a moisture meter offers some potential as an alternative to current methods of assessing maturity, the Delmhorst G-6c meter does not appear to be suitable. Other moisture meters, designed for measuring grain of high moisture content but still small, portable and easy to use, should be assessed for the purposes of maturity evaluations in breeding programs.

A second consideration of the use of such a moisture meter is the effect of sampling upon the values obtained. The reliability of the Delmhorst G-6c readings is dependent upon the size of sample tested. Kernels from only one to three heads are needed to obtain a reading. In this experiment, a mixed sample of kernels taken from ten heads was used. Further testing would be required to determine the optimal sample size.

2. Barley

The six barley cultivars demonstrated a wide range of maturities (tables 47 and 48). Classification of the genotypes differed slightly for each of the four measures of maturity. None of the four alternate measures gave rise to a grouping of the cultivars identical to the control method. These discrepancies of evaluation of the cultivars demonstrate the difficulty of reliably detecting small differences in

maturity among barley as well as wheat genotypes.

If a plant breeder were willing to accept some degree of misclassification, correlation analysis suggests that for barley field rating, days from seeding to heading and days from seeding to swathing ripeness provided the best agreement with the control method (table 49). The Delmhorst G-6c reading demonstrated much poorer correlation with days from seeding to 35%mcwb.

Assessment of the Delmhorst G-6c in barley was similar to that in wheat. The moisture meter was not very accurate when compared to standard methods as evidenced by a highly significant t-value. However the high correlation between the moisture meter readings and standard determinations suggests that the Delmhorst G-6c meter readings erred in a consistent manner. When applied to grain samples of high moisture content (greater than 30%mcwb), the Delmhorst G-6c appeared less satisfactory for evaluating lines for relative maturity (table 49). Thus for barley as for wheat, once-over testing for moisture content at physiological maturity of the earliest cultivar is potentially a powerful method of selection for particular maturity classes. However, alternate moisture meters and sampling procedures should be tested before such a method can be adopted for a breeding program.

B. Drying Curves

Meredith and Jenkins (1975) have proposed that an active physiological process was responsible for the loss of moisture from ripening kernels. The drying rate was to have described this metabolic function. The authors also suggested that the effects of weather were

transitory. Precipitation may cause temporary fluctuations in moisture content, but does not affect the rate of drying.

Regression analysis was used to test this model of Meredith and Jenkins (1975) on the drying curves constructed for seven wheat and six barley genotypes. As stated in the results section, a multiple regression approach using %mcdb data was selected over the simple and polynomial models to analyze the wheat and barley curves (tables 50 and 56).

The use of multiple regression analysis assumed that the drying process was basically a constant linear function. It is possible that this assumption of linearity may be an oversimplification. The over all shape of the drying curve may be slightly curvilinear reflecting the influence of climate. The drying curve might be expected to be slightly concave under cooling conditions and convex for warming conditions over the growing season (Dodds and Pelton, 1969). Similar testing over several diverse locations and seasons could prove or disprove this statement concerning the influence of climate upon the drying process.

In contrast to the effects of climate, the influence of daily, local weather was assumed to be transitory and random. The effects of weather were thought to cause deviations from the drying curves estimated by multiple regression analysis. Because of the fluctuations in moisture content caused by the weather, a good fit of the drying curves is possible only if the weather conditions are constant.

1. Wheat

The use of multiple regression analysis would appear to be a satisfactory method of describing mathematically the drying process.

For each of the seven wheat genotypes, more than 90% of the variation about the mean could be explained by multiple regression analysis (table 51). Implicit in this statement is the further assumption that the Meredith and Jenkins model is satisfactory for explaining the drying process in wheat.

The four regression coefficients, derived by multiple regression analysis, can be used to characterize early and late maturing genotypes (table 51). Early genotypes, like Park, are characterized by a lower initial moisture content (smaller b_0 value), than later genotypes like Glenlea and Pitic 62. This is likely due to the earlier heading (table 45) and anthesis dates of the earlier genotypes . Somewhat surprizingly the earlier genotypes had slower drying rates (smaller b_1 and b_2 values) than the later cultivars. Early types also differed from the late genotypes for the b_3 values. Early cultivars switched from the faster to the slower drying rates earlier than the late cultivars. These conclusions are based upon a limited sample of genotypes and would be more sound if many lines were similarily characterized.

The attainment of physiological maturity is dependent upon both the rate of drying and the date drying is initiated. Selection of early types should include selection of early heading or anthesis dates. The selection of fast drying types would appear less important for determining earliness. Selection for earliness on the basis of heading date is also more practical, and easy to accomplish in a breeding program dealing with many lines. Scoring drying rates would require at least two separate measures of moisture content. Estimation of drying rates on the basis of two or only a few points cannot be expected to be reliable. Weather parameters, especially rainfall, would have a substantial influence on absolute values and

estimated drying rates. Thus selection for a maturity class, such as earliness, is more feasible when selection is based upon heading or anthesis dates. Alternate methods such as the cessation of translocation to the kernels as proposed by Lee et al. (1977) may also be useful.

2. Barley

The multiple regression analysis as outlined by Draper and Smith (1966) provided a good fit of the drying curves of the six barley cultivars (table 56). The fit obtained for the barley genotypes was less than that for the wheat genotypes from comparison of variation explained values (tables 51 and 57).

It was possible to distinguish among the six barley genotypes on the basis of the b_0 and b_2 regression coefficients only. The drying rate (b_1) was similar for all cultivars. This result contrasted with the results from the wheat experiment but agreed with results found in maize (Gunn and Christenson, 1965). Early barley cultivars from this test, like Olli, were characterized by low initial moisture contents (b_0) and slow or nonexistent rates of drying during the second drying period (b_2). Late cultivars, like Galt and Jubilee, demonstrated high b_0 values and fast drying rates during the second period of drying (b_2). Again, this characterization of early and late cultivars was based upon a restricted sample size. A large number of barley genotypes should be similarily analyzed before early qualities can be properly defined for this system.

This characterization of earliness suggests selection for earliness or a particular maturity type can be made on the basis of heading date or on the basis of relative moisture content during maturation such as has been proposed in the maturity measures section,

with the modification that %mcdb values be used in place of %mcwb values. For reasoning similar to that presented for the wheat test, selection of maturity types based upon drying rates is not practical.

3. Influence of Weather Parameters on the Drying Curves

The local weather conditions were assumed to cause transient fluctuations in moisture contents, or deviations from the underlying drying rate. Both weather parameters adding moisture to the kernel, such as precipitation, relative humidity and evaporation, and those concerned with the removal of moisture from the grain, like wind, temperature, solar radiation and evaporation, affect the magnitude and sign of the residual values. It was reasoned that the effects of the weather parameters may persist for several days. Therefore the influence of various weather parameters one to five days prior to sampling as well as on the day of sampling were analyzed. It should be noted that fluctuations in the weather parameters will not be able to wholly account for the residuals generated from the drying curves. Deviations due to transient fluctuations in metabolic processes and random, unexplained error, not attributable to weather conditions will also contribute to the residual values.

The approach used to formalize the relationships between the weather parameters and the residuals was basically that of the least squares method of regression analysis. Simple correlation values between the weather parameters and the residuals provided the basis for selection of the ten weather parameters most likely to exhibit an influence upon the residual values. Many of the simple correlations for both the wheat and barley data sets were significant or highly significant. Not surprizingly, weather parameters from one day prior

to sampling generally demonstrated the highest correlations with the residuals. However, in all 90 cases, the magnitude of the correlation value was small and the variation explained was very low for any one variable (tables 52 and 58).

Simple regressions of the wheat and barley residuals on weather parameters taken individually tended to confirm observations made from the simple correlation values. Although a significant proportion of the variation of the residuals could be attributed to related fluctuations in some of the weather parameters, a large proportion of the variation of the residuals remained unexplained. This was true of both the wheat and barley residuals (tables 53 and 59). Residuals from the barley drying curves appeared more subject to the influence of the weather parameters than those derived from the wheat drying curves, as evidenced by the greater percent variation explained values. For wheat, the variables PPT-1 and LGL-1 most commonly provided the best fit of the residuals (table 53). Not unexpectedly these two variables were highly significantly and negatively correlated (table 54). For barley, EVP-1 and PPT-1 often provided the best fit of the residuals of the six cultivars (table 59). These two parameters were also highly significantly and negatively correlated (table 60). For the two late barley cultivars, BRS-5 gave the best fit of the drying curve residuals. This result was unexpected and difficult to explain.

Multiple regression models relating several weather parameters to residual values were analyzed. It was reasoned that several weather parameters acting simultaneously at a given sampling date determine the magnitude of the deviation from the expected moisture content value. The weather parameters tested, particularly those taken from the same

day were highly interdependent. Correlation values among the parameters were often highly significant (tables 55 and 61). This reduced the number of parameters that could be included in the same multiple regression analysis to four or five for both the wheat and barley analyses. Use of the multiple regression approach was able to improve the fit of the residuals in both species (tables 55 and 61). For the barley residuals, a substantial proportion of the variation could be explained by the application of multiple regression analysis (table 61). The effectiveness of the multiple regression approach in wheat was less pronounced (table 55). Thus, it would appear that a superior fit of the drying curves is possible for the wheat data, but that for the residuals, the barley residuals were better described by fluctuations of the weather parameters than were the wheat residuals.

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Appendix: 1 Days from Seeding, Mean Moisture Content (averaged over all replicates and genotypes), and Mean Moisture Content (averaged over all replicates) of Seven Wheat Genotypes for each Sampling Date

Days from Seeding	% moisture content - wet basis							
	Mean	Park	Neepawa	Norquay	Glenlea	Pitic 62	70M009002	70M110001
94[1]	54.374	50.734	52.142	53.248	56.657	59.847	54.576	53.414
97	49.440	46.458	47.432	48.508	52.255	54.370	48.808	48.250
101	44.280	39.817	45.220	44.333	46.165	48.123	42.594	43.706
104	40.319	35.375	40.676	39.902	43.843	44.567	38.843	39.028
108	34.216	27.991	33.249	33.415	40.137	40.820	31.202	32.699
110	31.764	22.256	31.508	30.698	37.726	39.550	29.592	31.021
112	35.896	31.814	35.578	34.987	40.160	39.652	34.704	34.381
115	23.909	19.106	21.377	20.163	31.084	28.811	22.538	24.282
117	20.678	19.144	17.662	18.317	24.345	24.872	20.458	19.948
119	19.786	18.599	19.476	19.335	20.761	21.164	19.900	19.269
121	17.384	15.887	15.476	15.493	22.488	17.101	18.973	16.271
123	28.396	27.370	28.070	28.812	28.915	28.914	27.669	29.017
125	20.941	19.930	19.964	21.582	21.612	21.197	21.387	20.902
127	17.491	17.386	17.216	17.475	18.244	17.314	17.323	17.476
130	15.951	15.818	15.706	15.909	17.486	15.052	15.767	15.919
133	15.811	15.944	15.819	15.888	16.957	14.860	15.476	15.732
138	14.544	14.888	14.847	14.417	15.010	13.938	14.184	14.521
141	16.755	16.838	16.699	17.754	16.904	16.332	16.376	16.384
Mean	27.885	25.297	27.118	27.235	30.598	30.360	27.243	27.346

[1] August 9

Appendix: 2 Days from Seeding, Mean Moisture Conteht (averaged over all replicates and genotypes), and Mean Moisture Content of Six Barley Genotypes (averaged over all replicates) for each Sampling Date

Days from Seeding	% moisture content-wet basis						
	Mean	Olli	Gateway 63	Conquest	Bonanza	Galt	Jubilee
81[1]	52.902	53.645	52.234	52.885	51.375	54.157	53.115
87	52.036	45.093	48.889	52.987	52.820	56.605	55.819
90	50.479	44.071	47.577	51.991	50.521	54.394	54.324
94	44.565	34.230	42.688	44.879	45.220	49.915	50.459
97	31.884	19.431	31.296	28.670	30.566	38.871	42.472
99	22.123	14.933	18.392	23.563	18.989	28.248	28.615
101	18.384	14.445	16.164	19.696	17.968	19.750	22.283
104	19.816	18.273	18.574	19.506	19.448	20.634	22.463
106	15.306	13.388	14.786	16.593	14.401	17.424	15.246
108	15.307	14.854	14.888	15.308	15.807	15.165	15.820
112	29.729	31.589	29.394	31.504	32.400	25.873	27.615
115	16.985	16.802	17.051	16.692	17.306	16.763	17.293
117	17.439	17.664	17.209	17.225	17.324	17.934	17.279
119	18.951	17.967	19.611	18.949	19.078	19.617	18.475
121	14.691	14.696	14.763	14.605	14.575	14.678	14.828
125	22.593	21.098	22.526	23.548	22.078	22.809	23.499
133	14.429	14.393	14.254	14.960	14.914	13.910	14.142
Mean	26.919	23.916	25.900	27.268	26.752	28.632	29.044

[1] July 27